NUCLEAR ENGINEERING

VOL. 2 NO. 11 FEBRUARY, 1957

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EKCO nucleonics & electronics

information sheet

REACTOR PERIOD METER

Types 1389B 1513B

The EKCO reactor period meter is connected to a neutron sensitive ionisation chamber located near the reactor. The input current, which is then displayed on a 5″ panel meter, is representative of the reactor power level. The second 5″ panel meter shows the rate of change of input current and is calibrated in seconds to indicate the time taken for the neutron flux to increase or decrease by a factor of two. A positive reading indicates an increase and a negative reading corresponds to a decrease while the intermediate 'infinity' reading represents a steady flux with no change.

The instrument incorporates a D.C. amplifier which is designed to measure and indicate on a logarithmic scale very small direct currents over a range of seven decades. This is followed by a differentiating amplifier which measures the rate of change, this being indicated as time taken for the input current to change by a factor of two. Provision is made for giving warning when an adjustable predetermined rate of change is exceeded.

Trip facilities on both positive and negative doubling times provide for automatic operation of the reactor warning and safety circuits. 'Fail-safe' precautions ensure that failure of a major component trips the alarm facility. The equipment comprises two units—the Main Unit and the Head Amplifier. Two different versions give alternative facilities as detailed in the Specification.

SPECIFICATION

	Type 1389B	Type 1513B
Input Current (Accuracy ±10%)	5×10^{-12} to 5×10^{-5} amps	$5 \times -^{12}$ to 5×10^{-5} amps
Doubling Time (Accuracy ±5%)	—80/infinity/+20 secs.	—20/infinity/+5 secs.
Trip-Setting Range	Between 60 and 20 secs., positive and negative	Between 15 and 5 secs., positive and negative

Controls etc: No controls are located on the front panel, pre-set and calibration controls being housed in an inset panel visible through a window in the covering door. Two telephone-type jacks are provided to permit checking and calibration of both the logarithmic D.C. amplifier and the period meter. Relay contacts are connected to plugs at the rear of the instrument for incorporation in warning and trip circuits. A lamp on the front panel is extinguished when the trip circuit operates. Sockets are provided for the connection of external meters and/or recorders if required.

Power supply: H.T. supplies are stabilised and incorporate thermal delay switching which protects the valves by delaying the application of H.T. until the cathodes reach operating temperature. The equipment operates from A.C. mains of 110–120 Volts or 200–250 Volts, 50/60 c/s.

Construction: The main unit is built on a standard rack-mounting panel, size 19″ x 10½″ (48.3 x 26.7 cm.) and is approximately 14″ (35.5 cm.) deep. The head amplifier contains the input valve and is a sealed casting which can be mounted either within the main unit or adjacent to the ionisation chamber.

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NUCLEAR ENGINEERING VOL. 2 NO. 11 FEBRUARY, 1957

EDITORIALS

Ministry of Power

ONE of the most important changes brought about by the formation of the new government is the appointment of a Minister of Power of Cabinet rank. By this appointment, the Government has acknowledged our ever-increasing dependence on power availability to maintain our industrial progress and the necessity for co-ordinating all available sources at the highest level.

The extent to which co-ordination and exploitation can be effective is, however, dependent upon a number of factors, chief amongst which are the shortage of materials and man-power. These are the same limitations that are imposed on many expansion programmes. On the materials side steel is likely to be the major bottleneck—steel plates for pressure vessels and heat exchangers and heavy sections for structural work, etc. —steel is likely to be of greater significance in planning the programme than uranium and graphite which, being largely confined to atomic energy have received intensive attention over the past years. It is highly appropriate, therefore, that the new Minister, Lord Mills, will also be responsible for supervising the iron and steel industry, for only by an appropriate expansion in this industry can a significant expansion in the nuclear power programme, over and above that already anticipated, be contemplated.

White Paper Out of Date

The White Paper of February, 1955, calling for the installation of 2,000 MW generating capacity by 1965 has been recognized for some time as being out of date, largely as a result of the advances that have been made in design. By a 50% increase in the original number of stations planned, an increase in generating capacity of at least threefold can be achieved.

A dramatic increase, however, in the number of power stations built cannot be accomplished by the publishing of a second White Paper only. The raw materials must be made available first, or at least plans must be under way to ensure that materials are forthcoming the instant they are needed. These nuclear stations will require twice the capital investment of conventional stations and, whilst the investment from the point of view of finance may be no problem, higher capital cost implies higher consumption of these scarce commodities, steel and labour. We also cannot afford to disrupt all other engineering undertakings, and at all costs the export trade must not be neglected, although the export of designs need not necessarily involve materials.

Continued Dependency on Coal and Oil

We must also remember that the date at which all new installed capacity is nuclear cannot be advanced to nearer than 1961—four years from now—and that another five years must elapse before our electricity can be supplied from predominantly nuclear sources, and even that assumes that all nuclear stations can be operated at a high load factor. For another ten years then at least, coal and oil will be major sources of electrical energy and are likely to be our main sources of low-grade heat for a much longer period.

It is imperative, therefore, that the energy situation be viewed as a whole and integrated with the raw materials situation. Lord Mills' major decisions will not only concern how much money, but how much effort should be expended, and on what, and in what order. He must also take into account the demand from overseas, and whilst generating capacity at home cannot be neglected it would be wrong to indulge in an extravagant building programme which in any way limited selling capacity abroad. The establishment of priorities is no simple matter, particularly when the potentialities of the advanced systems are in permanent state of flux. Long-term planning at this stage is, of course, essential, but it must be so guided that we are not irrevocably tied to the Calder Hall type for too long a period in case one of the new systems should suddenly forge ahead at high speed.

The new Minister has a difficult task before him, but our standard of living will depend upon the wisdom of his decisions. His previous experience should stand him in good stead, but he will need the support of all those in a position of authority and their understanding. At the same time, he can be confident that industry, in its turn, is in a position, particularly on the nuclear side, to enter into imaginative programmes and to put into the construction and development of nuclear power stations not only the material resources that would be put at its disposal but a tremendous body of enthuiasm and energy. Of all fields of endeavour covered by industry today, atomic energy is in the strongest position to demand that extra effort, both in time and thought, that can so materially affect a programme's development rate.

Public Inquiries

BY the time this issue is published, both public inquiries concerning the establishment of a new atomic energy station in Dorset and the site of the South of Scotland Electricity Board's station will have been concluded. In many ways these public inquiries could be regarded as an unnecessary waste of public money and time, if the conclusion in these two cases is that work can go ahead on the sites under discussion. The Bradwell inquiry caused a lot of concern amongst the tendering companies and at times generated a certain amount of discord. The result, however, was that work should go ahead as originally planned.

There would be few in this coutry who would wish to deny the rights of private citizens to protest against the invasion of their established domains and the alteration in the local amenities by such projects, or would deny that if such rights were taken away that there would not be a steady change in the attitude of bureaucratic bodies towards the acquisition of land and the selection of sites. We have commented before on the absence of steam-rollering techniques which might have been adopted by the U.K.A.E.A., and the S.S.E.B. in its turn, has been entirely proper in its approach to the question. It would be wrong to assume that this would have still been true if the possibility of a public inquiry, followed by an adverse decision, had not been present, and the adage that "absolute power corrupts absolutely" is not to be taken lightly.

It must be remembered also that these are atomic energy installations which are under consideration and, in spite of the exhibitions, talks and lectures that have been given throughout the country, many people are suspicious of these developments and, even if not suspicious, at least feel in the dark, and would like to know more of the potential dangers that exist. These public inquiries do, in fact, provide an opportunity for the ordinary man to ask questions publicly and to receive public answers, which otherwise could not be aired. Some of the questions may appear facile, irrelevant and even stupid to those who are familiar with the processes involved, but they are nonetheless representative of the questions that the man in the street would like to ask and it is only right that they should be answered accurately and sincerely. As time goes on, the significance of the atomic energy side will decrease and the problems associated with new sites will be the same as those associated with the siting of conventional stations.

Leaving aside then the radiation and "explosion" hazards that concern the public, it is likely that amenity problems will continue to exercise the minds of those directly concerned; but if we are to have power stations, if we are to make industrial progress, somebody must always suffer, and if the number can be kept to a minimum that is the best that can possibly be achieved. This problem will become more acute as time goes on. It would be a pity, however, if it was necessary to go through the rigmarole of a public inquiry for every new installation, and it would seem that the machinery of normal local government could be made more effective by increasing the influence of the individual through his Parish Council.

Sub-Contracts

WITHOUT exception, the four main groups who tendered for the Central Electricity Authority and South of Scotland Electricity Board stations had already invested a large amount of capital in the ordering of components, such as cranes and steel plate, even before the contracts were placed. If the tight building schedule laid down in all cases is to be adhered to, this was, of course, essential. It is indicative of the confidence of the groups that they were prepared to expend so much money at such an early date—it is understood that some of these sub-contracts were placed as much as a year prior to the final contract date—and it also gives a measure of the enthusiasm with which these groups are undertaking the building. Already work at two sites is under way. Ground was broken by the A.E.I.-John Thompson Nuclear Energy Company at Berkeley as early as January 7 and a sod-cutting ceremony was held by the N.P.P.C. at Bradwell on January 18. These have not been merely formal openings of the site, but were the beginnings of full-scale operation and already, particularly at Berkeley, much of the initial clearing and road construction is complete. Clearly, the competitive spirit which was so apparent prior to the placing of the contracts is by no means dead, and the race to have the first in operation will be very hard run. We have emphasized above how important this keenness can be.

In spite, however, of the extent of the work that has already been sub-contracted and the number of orders that have been placed (again with all the groups), a number of items of design have yet to be finalized and further contracts for these first power stations will continue to be placed, probably over the next 18 months. In some instances, companies have had to tender to more than one main contractor, whilst their production capacity, at least at present, is not able to fulfil the demands of more than one; such companies are now faced with the problem of rapidly expanding their manufacturing capacity, but in many cases these sub-contracts will have to be placed elsewhere. There is still a lot of scope for new companies to enter the field. In fact, unless more companies are prepared to undertake work for the atomic energy power programme, present commitments concerning time schedules will be met with the greatest difficulty. Further large-scale expansion is only possible if more and more companies are prepared to contribute.

Comments on the News

HARWELL NATIONAL RESEARCH CENTRE

An important step in the pure research facilities of the U.K. is likely to be taken in the near future when the Treasury is expected to approve the establishment of a National Centre for Nuclear Physics. The first official report of this project was given by Professor Mott, Cavendish Professor of Experimental Physics, in a lecture to the Science Masters Association in Cambridge at the beginning of January. The projected centre is to be at Harwell outside the security fence, and the main building will probably be built on the airfield not far from the site of the linear accelerator. The programme would be worked out by the A.E.A. in co-operation with the universities. The centre, whilst having its own laboratories, lecture halls and equipment, would have the facilities of the experimental reactors at Harwell but the main work of the establishment would be centred on a powerful synchrocyclotron designed to compete with the U.S.S.R. and U.S.A. installations.

COLD HD REACTION

If the new discovery announced by Dr. Alvarez of the University of California Radiation Laboratory has no ultimate power significance, it does at least show that there is still room for fundamental discoveries which will surprise the scientific world and for discoveries which can change the whole face of the atomic energy field. In a paper to the American Physical Society, Dr. Alvarez discusses the results of experiments carried out with the Berkeley accelerator (the Bevatron) which have shown that fusion can be brought about by what has been termed a catalytic process. In the experiments μ mesons produced by the accelerator were allowed to bombard a hydrogen bubble chamber—the modern counterpart of the cloud chamber—in which visible tracks of tiny bubbles are formed by charged particles.

The μ meson is a particle which carries unit negative charge and has a mass two hundred times that of the electron. It is capable of forming a mesonic hydrogen atom in which the normal planetary electron is replaced by the μ meson. As a result of the much larger mass, the orbit of the μ meson is much smaller than that of the electron; probability of interaction between nuclei is correspondingly increased. The meson has a preference for the deuterium atom as against the hydrogen atom (proved by enriching the liquid in deuterium) and a number of $HD \rightarrow He\,3$ reactions have been observed. In the process the μ meson is ejected and is available for the displacement of another orbital electron, which in turn can take part in an HD reaction. At least one such double reaction has been observed. Unfortunately, the life of the μ meson is measured only in microseconds and at present it can only be produced with very high-voltage (and very expensive) accelerators. On the other hand, a Russian scientist, Alikhanian, has reported the discovery of a heavy particle with a single negative charge with a much longer life. This could also presumably enter into reactions in the same way that the μ meson has been observed to do.

It would be misleading at this stage to state that such a long-lived heavy negatively-charged particle does, in fact, exist and more misleading to suggest that the discovery of Dr. Alvarez will lead to developments of a fusion reactor which can be initiated at ordinary thermal temperatures or lower. What we can say at this juncture, however, is "that there are more things in heaven and earth . . ." and that we must be prepared at any time to completely reconsider our attitude towards atomic energy developments. At the same time, we can be assured that the interval of time between such a discovery and its exploitation in terms of working power reactors will be considerable, and that there is no real likelihood of the fission reactor being challenged for a great many years.

SIR JOHN AND SHIP PROPULSION

Statements made by Sir John Cockcroft in an address to the Management Course of the National Industrial Conference Board in Paris on January 20 have resulted in the potentialities of nuclear power for ship propulsion being generously highlighted. The position, however, has not fundamentally changed over the past few months and no decision can be taken yet on the type of power unit that is likely to prove the most economical. It has been known for some time that the organic-moderated reactor would "if technically feasible" (quote) have the advantage of lower fuel costs than the PWR. The high-temperature gas-cooled reactor could also bring the advantages of higher operating temperatures and lower pressures, but with neither of these two reactor systems has even a zero energy unit been operated; as Sir John implied, the feasibility study is not complete. A significant change has taken place, however, in the general approach towards the propulsion problem marked by an increase in interest of both the A.E.A. and shipbuilders and ship-owners over the past months. A continued rise in the effort that is devoted to ship propulsion will undoubtedly be reflected in a rapid advance in the accumulation of knowledge. The building of a nuclear-powered ship cannot begin immediately therefore—we have already pointed out that valuable operational experience could be obtained immediately on control mechanisms under simulated conditions—but the more people that are actively considering the many varied problems that arise the more rapidly will they be solved.

U.S.A.E.C. CONTRACTS

The U.S. Atomic Energy Commission's responsibility for the operation of the Federal atomic energy programme is now in its eleventh year, its tenth anniversary being January 1, 1957. The scale of its work has, of course, increased very rapidly over the past ten years and figures have been published recently of the reactor projects that have been put in hand during 1956. During the past year industry began construction on, or received contracts for, the building of 59 reactor systems. Of these, 29 were for power and 30 for research. The power reactors can be broken down into 14 for naval purposes, six land-based demonstration power systems for utility companies, four prototype power units for the A.E.C., four reactor units

for export and one contract for the propulsion unit of a merchant ship. Of the 30 research reactors, nine were for the Federal Government, 14 for export and seven for buyers within the U.S. These 59 reactors are in addition to the 17 contracts completed or nearing completion which had been awarded previously. These comprised seven propulsion units for the Navy, three power plants for the Federal Government, four for the utility companies and three research reactors. Over and above this should be included those contracts placed for aircraft-propulsion units.

The overall scope of the U.S. programme is continually widening and efforts are being made to bring more companies into the field. The A.E.C. has recently issued a further invitation (the third) for proposals to augment the power development programme and in this instance no deadline date has been made. The second formal invitation resulted in seven proposals being submitted, of which four have been accepted, and discussion is under way to finalize agreements. These are for a closed-cycle boiling-water reactor plant of 22 MW electrical capacity, an aqueous homogeneous plant of 5-10 MW electrical capacity, a heavy-water-moderated sodium-cooled plant with 10 MW electrical capacity and an organic-moderated system of 12½ MW capacity.

Three proposals were turned down. The City of Holyoke, jointly with the Ford Instrument Co., had proposed a gas turbine plant of 12.65 MW electrical capacity using nitrogen as the heat-transfer medium. This was rejected on the grounds that the gas-cooled reactor experiment was not sufficiently advanced for the basic feasibility studies to have been completed. The City of Orlando proposed a liquid-metal-fuelled reactor with an output of 25-40 MW electrical output. The Commission similarly decided that it was a premature proposal and should await further results from the existing liquid-metal-fuel experiments. The University of Florida proposed a pressurized light-water reactor designed for 500 kW output to be used partly as a research reactor, but this was rejected on the grounds that such a study would do little to advance the overall knowledge of this type.

EXPORT OF KNOW-HOW

At a Press conference before Lord Chandos, chairman of the A.E.I., left on a visit to Canada and America he stated that Canada offered considerable potential for the export of nuclear reactor know-how. He pointed out that Canada has its own steel industry and a number of civil engineering organizations and will in the near future be requiring nuclear reactors to augment its existing electrical capacity. By the export of know-how, generating equipment, certain specialized switchgear and instrumentation, a valuable market can be satisfied without endangering our own nuclear building potential. Questioned on whether he was prepared to discuss the export of know-how only, leaving the customer to supply all his own material and equipment, he replied that he was prepared to discuss such a contract but would not be enthusiastic. Another member of the consortia has indicated that the export of know-how without the export of generating equipment at the same time cannot be a worth-while proposition and would not be seriously considered. Certainly with large base-load stations which can only be purchased by highly industrial organizations, who are capable of absorbing a large amount of electrical capacity into existing systems and who can operate the stations at high load factor, there is always likely to be an indigenous industry capable of supplying those materials which would be in short supply if the whole of the work was carried out from the U.K. Export in these circumstances can offer a valuable return for the effort that has been put into development of designs with the minimum material drain on our resources. The dangers of selling designs in this way are small. The purchasing country may at a subsequent date take these designs as the basis of its own programme, but by the time the designs can be absorbed in detail and the essential fabrication experience gained the designs of the exporting company should have advanced considerably. In any case, it is better to export designs and develop a "buy British" feeling today rather than risk such markets falling into other hands.

B.N.E.C EXTENDS MEMBERSHIP

At a meeting of the board of the British Nuclear Energy Conference on January 9, it was decided to admit to membership the Iron and Steel Institute and the Institute of Metals. The dependency of atomic energy developments on steel production has been discussed already in this issue, whilst metallurgists—with the agreement of the engineers—have been saying for some time that the speed at which advances can be made with the new reactors is almost entirely a function of the metallurgist. The invitation of the board is therefore highly appropriate.

The B.N.E.C. is now composed of seven institutions, but there will be still some notable omissions; for example, the Institution of Metallurgists and the Institute of Marine Engineers. The functions of both these bodies would appear to have a significant bearing on future developments in atomic energy and the exclusion of these bodies from the ranks of the B.N.E.C. must inevitably limit its effectiveness. The co-ordination of the work of the institutions in the atomic energy field is a desirable function, but only by an overall co-ordination can this duty be fulfilled properly. It would seem that the B.N.E.C. has a difficult compromise path to take. By over-limiting its membership, its efforts cannot be truly representative, yet by opening its doors to all comers there is grave danger of the Conference becoming unwieldy and unmanageable. A more strict definition of its terms of reference would assist in its future operation.

W. L. OWEN KNIGHTED

The New Year's Honours List always brings in its train its due measure of criticism for the omissions or inclusions which interested parties feel have been made. There will be none, however, who will not approve the conferring of a knighthood upon William Leonard Owen, director of engineering and deputy managing director of the Industrial Group, U.K. Atomic Energy Authority. Mr. Owen joined the Ministry of Supply's department of atomic energy production as director of engineering in 1949 and was appointed assistant controller, department of atomic energy production, in the following year. He had been a colleague of Sir Christopher Hinton with the Ministry of Supply for some years prior to the founding of the atomic energy programme and was concerned during the war with the building and modifications to existing Royal Filling Factories. He was awarded the C.B.E. in 1950.

There has been no one who has put in more time and effort in the construction and design of the Calder Hall power station; particularly during the final year the responsibility for the completion of the plant fell largely upon his shoulders.

Nuclear Engineering proffers its congratulations on this public recognition of his work.

Atomic Energy in Eastern Europe

by
J. F. CALOR

PART 3—EAST GERMANY

The research and power programmes are receiving extensive assistance from the U.S.S.R. The first nuclear power station of 70 MW will probably be a heavy-water reactor. The country claims to be the largest producer of uranium in Europe, the entire output being exported to Russia.

IN East Germany the development of atomic energy is regarded as one of the Government's priority projects. The decision to embark on a large-scale expansion programme was taken in November, 1955, when the East German Government decided to organize an extensive network of nuclear research, to build a 2,000-kW reactor in 1956 and to set in motion plans for the building of a number of atomic power stations.

The decision to proceed with nuclear development was taken by the Government after earlier assurances from the Soviet Union, who promised to sell the research reactor a 25-MeV cyclotron, radio-isotopes and fuel until East Germany could produce her own. The East German research reactor is expected to satisfy soon the country's entire demand for radio-isotopes.

To advise the Minister in charge of Atomic Affairs, a Scientific Council for the Peaceful Application of Atomic Energy was set up. Among its 21 members, the Council includes Stalin Prizewinner Dr. Barwich, head of the Central Nuclear Research Institute; Prof. Macke, head of the Nuclear Physics Faculty of the Dresden College of Technology; Nobel Prizewinner Prof. Herz, head of the Leipzig Physics Institute; Dr. von Ardenne, supposed to be the moving spirit behind the plan for making Dresden East Germany's nuclear centre; Prof. Hartmann, head of Dresden's Vakutronik works, which is believed to be doing pioneer work in isotope technology; and the physicists Rambusch and Leibnitz.

East Germany's chief atomic research establishment is the Central Nuclear Research Institute. This will house the 2,000-kW water-cooled research reactor which is similar to those the U.S.S.R. has exported to other Iron Curtain countries. Recent information indicated that the buildings at the research institute site—said to be in a northern suburb of Dresden—are still under construction, and the walls of the reactor building were not complete in September, 1956. Plans for the radio-chemical laboratories were still under discussion at the time, so it would seem that it will take longer than planned to complete the whole project, which is to meet East Germany's research requirements for at least the next 20 years.

A Heavy-water Power Reactor

Information about East Germany's first nuclear power station, which is to be imported from the Soviet Union, is also scarce, but the latest news, given by Vice-Premier Selbmann on the occasion of the opening of the atomic energy exhibition in Leipzig in November, 1956, is that it will be a heavy water reactor fuelled by natural and enriched uranium, with a rating of 70 MW.[1] Specific agreements concerning its planning, construction, delivery and operation have been concluded with the Soviet Government. The station is now probably entering the design stage and may be expected to be completed in about 1961.

The production of power from atomic energy is an urgent economic necessity for East Germany, in view of the projected high rate of expansion of electric power demand (rising at present at the rate of 9% per annum). East Germany's coal deposits, estimated at 25,000 million tons of lignite, would be practically exhausted in 40 years, assuming the annual coal output to increase at a rate of about 5%. By 1975, at the latest, a substantial proportion of power must therefore be generated in nuclear stations. Little is known about the details of East Germany's long-term nuclear power programme (which cannot in any case have yet been given its final form), but the recently reported figure of 3,000 MW of nuclear capacity to be installed by 1970 suggests that a substantial programme is being contemplated, roughly on the same scale as in Czechoslovakia.

The East German station will use the same reactor system as that to be built by the U.S.S.R. in Czechoslovakia, and in this connection attention is drawn to the rapid progress recently made by heavy-water reactors in the Soviet sphere. As late as the Geneva conference of August, 1955, Prof. Blokhintsev spoke of the disadvantages attendant on these reactors, the high cost of heavy water, and at another point emphasized the large amounts of energy consumed by blowers required to circulate the gas coolant. Although he mentioned other types of power reactor undergoing development in the U.S.S.R., he made no reference to heavy-water reactors. Barely one year later, Prof. Kurchatov, in his Harwell lecture,[2] made it clear that something like two large-scale power stations with heavy-water-moderated, CO_2-cooled reactors were to be built in the U.S.S.R. by 1960, while a little later it was announced that both Czechoslovakia and Germany were adopting the same system for the first generation from their own nuclear plants. Indications are that, much in the same way that the Calder Hall design has proved more economical than originally expected, the Alikhanov-Vladimirsky reactor (which may be so called because it is based most probably on the heavy-water reactors described at Geneva by Alikhanov and Vladimirsky) has become, in the course of rapid development, a much more economic proposition. It has been claimed that the use of carbon dioxide coolant has reduced heavy-water requirements for these reactors by one-third, and further advances may be expected when the present high gas temperatures (500°C) are raised even further.

Largest Uranium Producer in Europe

The fuel for East Germany's nuclear power stations will come from her own uranium mines, principally situated in Aue, in the Ore Mountains. The other uranium sources, in the Harz Mountains and the Thuringian Forest, are thought to be only of secondary importance. East Germany claims to be the largest uranium producer in Europe; the entire output is exported to the U.S.S.R. and it has been estimated by West German sources that the

Aue mines provide about 30% of total Soviet requirements.

The uranium mines are exploited by the Wismut Company—an enterprise which East German authorities describe as the joint property of East Germany and the Soviet Union. Vice-Premier Selbmann explained recently that the Soviet Union pays for the uranium ore concentrates delivered by Wismut as for any other export commodity, and the price fully covers production costs and the profit margin to which East Germany is entitled. The administrative board includes an equal number of German and Soviet representatives, and the company's chairman, said Herr Selbmann, is a German citizen. Herr Selbmann himself conferred East German decorations on General Bogatov and four other Soviet members of the staff of the Wismut Company some time ago. But it may be supposed that until 1953 the Wismut A.G. was purely Soviet owned, and its output shipped to the Soviet Union as reparation payments.

Research Results

East German spokesmen have on many occasions praised the good work of the country's nuclear scientists, without disclosing much detail about their activities. There was little or no nuclear research in East Germany in the early post-war years, but a considerable number of German scientists and other specialists were taken to the U.S.S.R. to work on Soviet projects. A number of them returned to East Germany in 1955 and 1956, and their experience adds considerably to East German nuclear resources. Dr. von Ardenne, for instance, who has spent ten years in the Soviet Union, recently published the results of 30 years' research into the physics of neutrons and ions, nuclear physics, ultra-microscopy and the physics of plasma.

Some time ago von Ardenne outlined some of the research discoveries East German scientists claim to have made in nuclear physics. These concerned, above all, uno-plasmatron and duo-plasmatron ion sources. For the first time, it was claimed, it had become possible with duo-plasmatron ion sources to obtain proton streams of several hundred milliamps. out of emission apertures of only 1.2 mm diameter. Another development was an ion source for medium-heavy ions and a precision mass-spectrograph of high definition with an image converter making mass spectra visible. A simplified magnetic isotope separator based on these ion sources—reported to be under construction in Dresden in December, 1955—was also claimed as a new feature. Both uno-plasmatron and duo-plasmatron ion sources were then scheduled for industrial production at Dresden.[3]

Dr. von Ardenne himself works mainly at the research institute of Dresden's rapidly expanding College of Technology (9,500 students in 1956). This college also has a nuclear physics faculty, whose central building is at present under construction. Dresden is also the seat of the previously mentioned Vakutronik plant, which has started small-scale serial production of radiation instruments. Among the staff are said to be scientists and technologists who studied isotope techniques in the Soviet Union. Also in Dresden is the X-ray and transformer works where Geiger counters are manufactured.[4]

In addition to Dresden, the physics institute at Freiberg's Mining College, for instance, is working on the development and improvement of instruments incorporating neutron sources to determine the constituents of rock formations. Jena University has its own isotope laboratory under a Soviet professor, working on isotope techniques in agricultural chemistry, and has been receiving monthly isotope consignments from Moscow. Nuclear research is also believed to be carried out at Halle University and the syllabus of Magdeburg's Heavy Engineering College includes a variety of subjects connected with nuclear physics and reactor technology, primarily to satisfy the needs of local heavy industry. These activities are in conformity with the Government's wishes that research and the training of nuclear scientists should be taught as widely as possible by universities, colleges and the Academy of Sciences. The Government has also decided that questions relating to nuclear physics should form part of the curricula of trade colleges and other schools.[5]

Scientists for Industry

East Germany's problem in the nuclear field is how to train scientists and technicians in sufficient numbers. An East German nuclear scientist estimated recently that the country would need more than 5,000 nuclear scientists in the next ten years; she will also need many more technicians and other skilled men. To train these men will be the object first of all of Dresden's College of Technology. Research workers will also be trained at the Central Nuclear Research Institute. Between 15 and 20 nuclear physicists are to be trained each year at an institute of nuclear physics in Rostock; but this is not expected to be ready before the end of 1958.[6] Other universities, especially Leipzig, will also take part in this programme. In any case, East Germany so far seems still very short of university-trained personnel, a state which cannot but be aggravated by migration to West Germany. Complaints that the importance of scientists and technicians in industry is underrated have not ceased since the 1955 national conference of scientists and technologists.

Amongst other difficulties in the development of a nuclear industry in East Germany may be counted the shortage of high-quality measuring and control devices in the chemical industry. Nonetheless, East Germany, with its traditional precision-instruments industry, is better placed in this respect than other Soviet-bloc countries, and is exporting nuclear instruments and equipment principally to the U.S.S.R., and also to Poland.

The current five-year plan envisages the large-scale use of radio-isotopes in biology, medicine and industry. The Ministry of Health has the advice of a special radiological research group. In Dresden three isotope laboratories are under construction, and at Berlin-Buch the Institute for Medicine and Biology specializes in isotope production. For the time being, however, most radio-isotopes are being supplied by the U.S.S.R. In the foreseeable future, it is forecast, all factories will contain equipment incorporating radio-isotopes.

International Co-operation

In the field of international co-operation in nuclear research, East Germany is, of course, closely associated with the Soviet Union and the Soviet-bloc countries in the Joint Nuclear Research Institute at Dubna, U.S.S.R. East Germany has also offered to make her knowledge and experience available to the International Atomic Energy Agency, which she feels entitled to join as "one of the world's largest producers of nuclear fuel". Whether or not East Germany becomes a member of the agency, the achievement of her nuclear goals will largely depend on the international situation, her own political future, and the resources which the Government will be able to devote to atomic energy developments.

References

[1] Allgemeiner Deutscher Nachrichtendienst (A.D.N.), July 20, 1956.
[2] *Nuclear Engineering*, 1956, **1**, 95.
[3] *Tribuene*, December 5, 1955; *Berliner Zeitung*, December 7, 1956.
[4] A.D.N., May 1, 1956.
[5] Report on S.E.D. Conference, issued March 29, 1956.
[6] *Berliner Zeitung*, July 31, 1956.

South of Scotland Nuclear Station

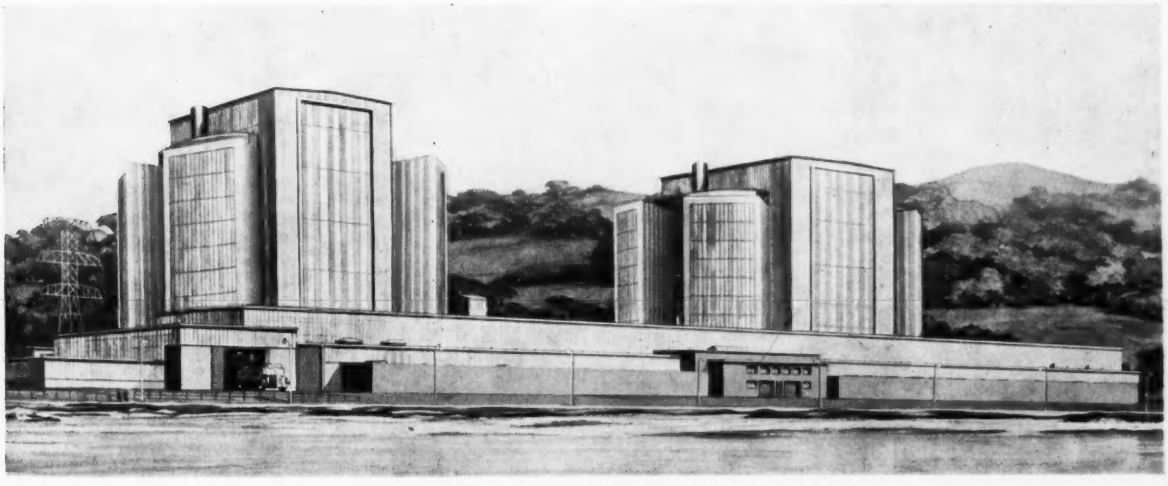
S.S.E.B. To Install 300/320 MW Available Capacity

THE South of Scotland Electricity Board has announced that they intend to place a contract with the G.E.C. Simon Carves Atomic Energy Group for the construction of a nuclear power station. The site for this station is not yet finally decided but permission is sought for its erection at Hunterston in Ayrshire. An alternative site will be selected if this permission is refused, but the siting will almost certainly be coastal to accommodate the large quantities of condenser water required. It is expected that ground can be broken in Spring or early Summer this year. The station will comprise two reactor systems, the first of which will be ready for commissioning trials towards the end of 1960, followed by the second some six months later.

The original specification for the station gave considerable scope to the companies tendering, in that total installed capacity was not defined, and the only significant conditions were concerned with the economics and with the safety and reliability of operation. Designs were, of course, to be based on the graphite moderated, gas cooled reactor as developed at Calder Hall, and the Atomic Energy Authority undertook the basic nuclear training of the design engineers and much of the basic research into the nuclear physics and engineering data. Departure from the established design features of Calder Hall was not discouraged, but the companies tendering had to bear in mind the limited experience available in the design and operation of nuclear reactors and in the site fabrication of large scale plant to exacting tolerances.

In the G.E.C. Simon-Carves design the basic characteristics of the Calder Hall type have been retained. The reactor is a graphite moderated reactor, fuelled with natural uranium contained in magnesium alloy cans and cooled by carbon dioxide gas circulated under pressure. The carbon dioxide gas raises steam in externally mounted heat exchangers which drive conventional type steam turbines. The vertical system of fuel channels and control rods has been maintained and the general shape of the reactor core is similar. Nuclear physics requirements indicate a cylindrical core with a height approximately equal to the diameter whereas heat transfer considerations indicate a slab type core. The compromise results in a cylindrical core with the diameter somewhat greater than the height. The main biological shield is of concrete although detailed dimensions are different, and the thermal shield which even at Calder was considered a refinement has been omitted. Many of the details also follow the Calder Hall precedents, such as the general operation of the burst slug detection gear; but, on the other hand, fundamental steps have been taken in advancing engineering design.

The Transart study of the design which appears as a supplement to this issue of *Nuclear Engineering* has been made exclusively available to the journal by the G.E.C. Simon-Carves Atomic Energy Group. It serves to point the essential changes that have been made in the design from those established for Calder Hall. Following the supplement and specification, the major aspects of departure are examined and the basic reasoning behind the designs established. Some of these changes will no doubt cause controversy and only after a lengthy period of operation can their success be finally gauged. At the same time it should be remembered that these designs by no means represent the ultimate that is possible in the development of the gas cooled type, but represent the first step from the prototype model at Calder Hall. One of the major problems has been the determination of how big a step can be taken at this moment, and whilst these designs will be completely finalized in the next few months by discussions between the customer and the supplier, plans are already in hand for further advances in the future.



Artist's impression of the nuclear power station to be built by the G.E.C. Simon-Carves Atomic Energy Group for the South of Scotland Electricity Board. The steam raising units have been enclosed.

The World's Reactors

No. 9—THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION

DESIGN AND CONSTRUCTION

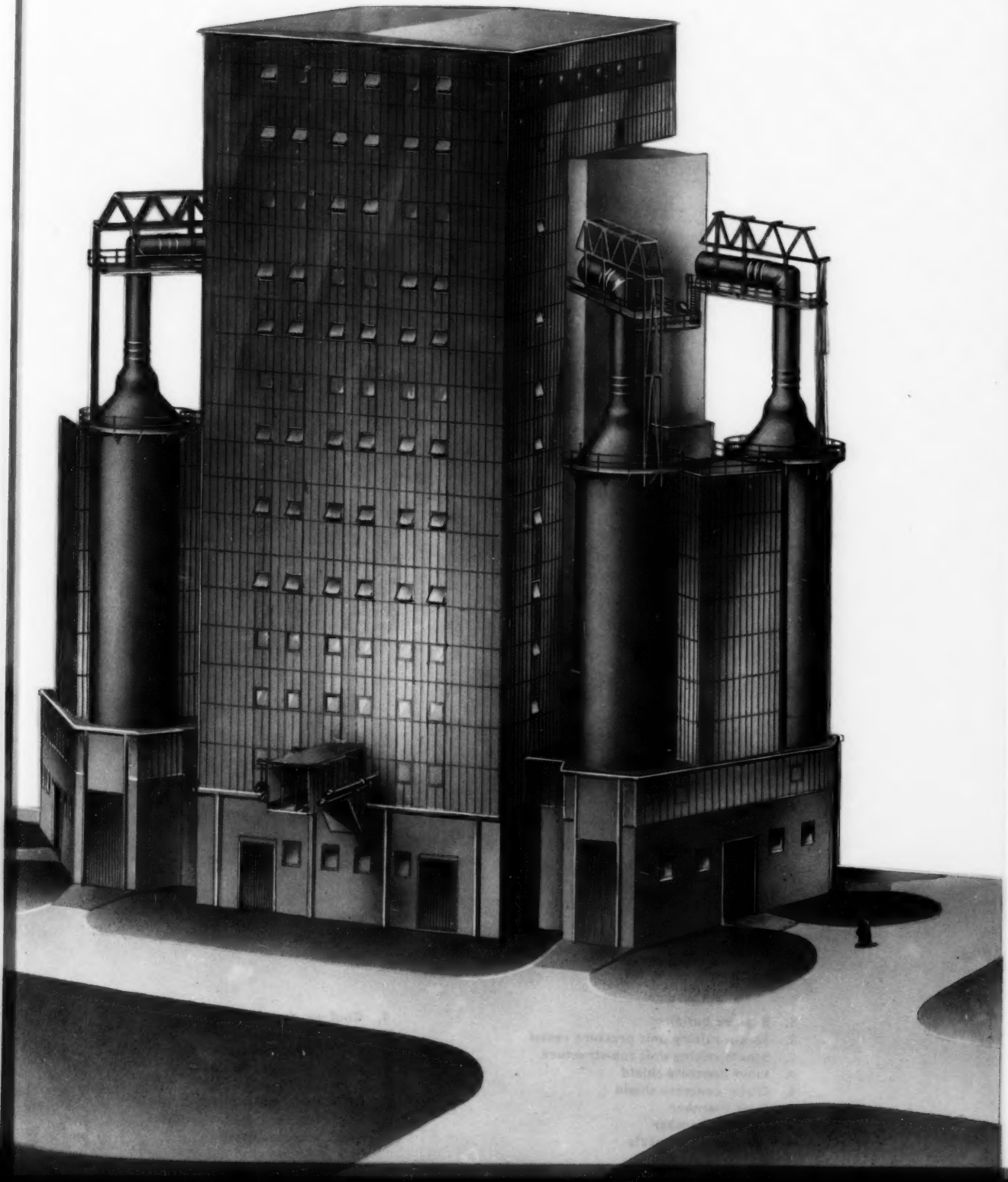
The G.E.C.-Simon Carves Atomic Energy Group, Erith, Kent.

comprising : The General Electric Co. Ltd.
Simon-Carves Ltd.
The Motherwell Bridge and Engineering Co. Ltd.
John Mowlem (Scotland) Ltd.

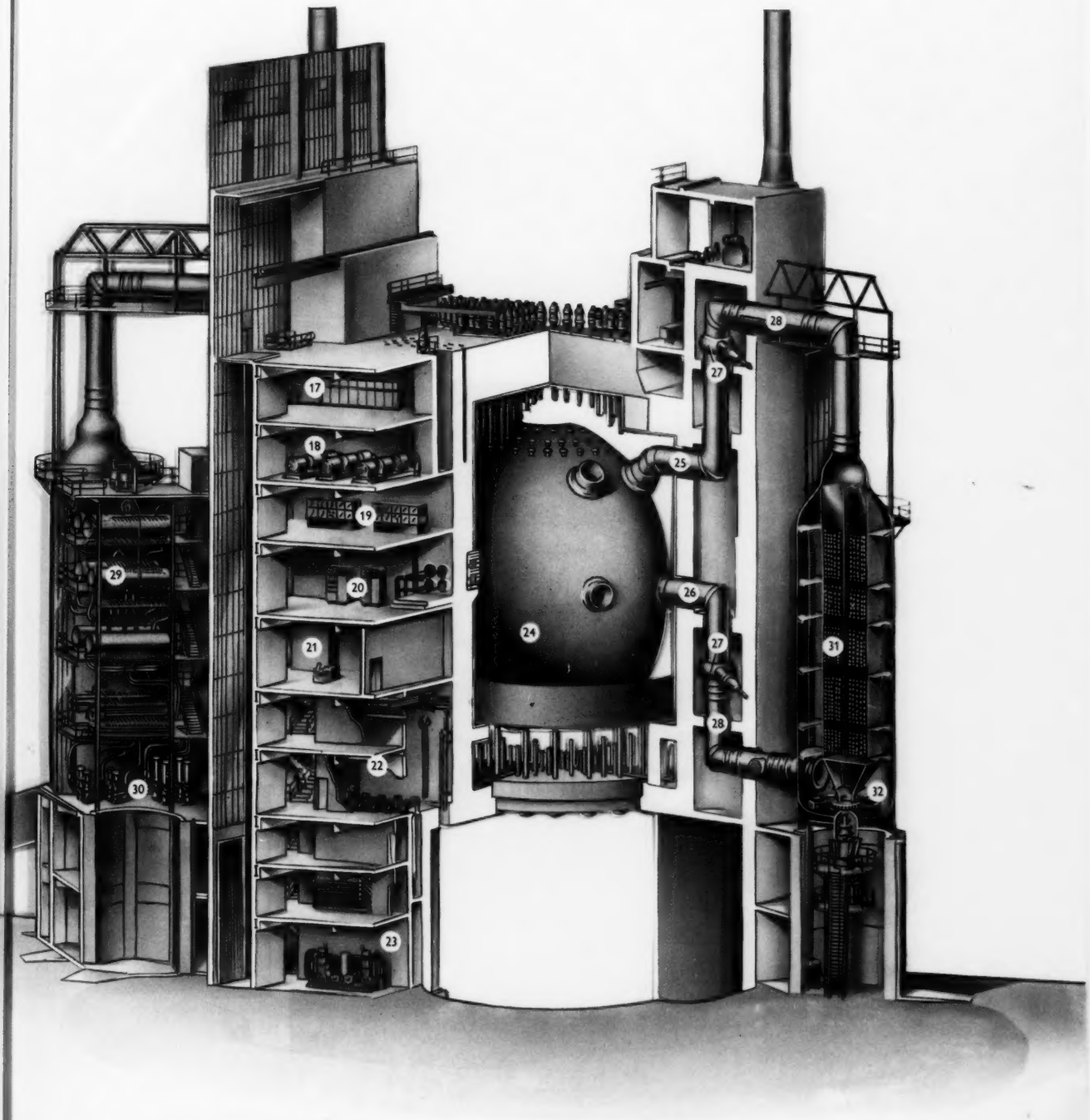
CONSULTING ENGINEERS TO S.S.E.B.

Kennedy and Donkin, 12 Caxton Street, London, S.W.1.

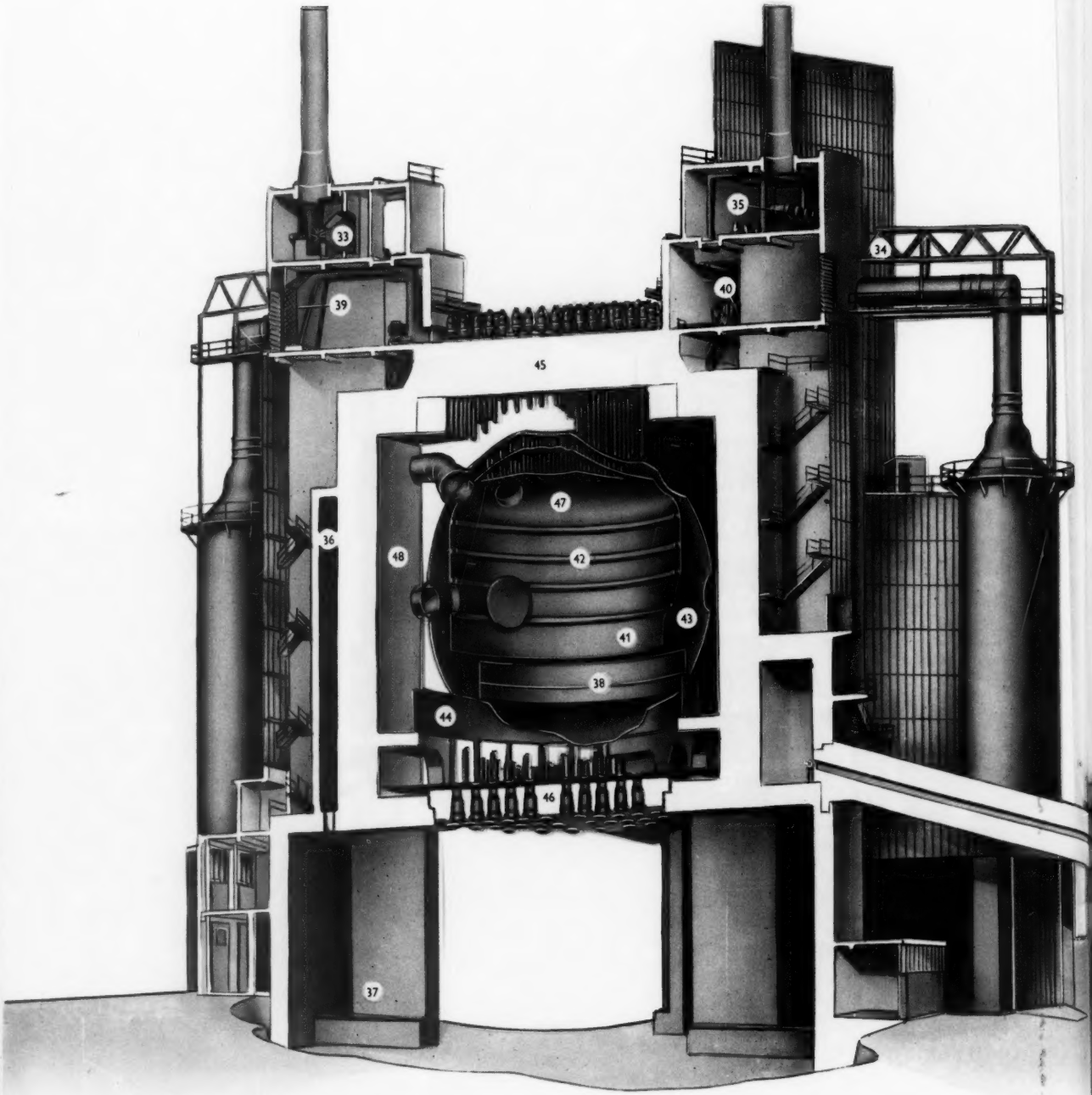
TYPE:	Thermal heterogeneous.
PURPOSE:	Power production.
LOCATION:	South of Scotland (Site to be decided).
CAPACITY:	Max. continuous electrical rating: 360 MW from two reactors and six turbo-alternator sets. Net electrical output: 300 MW rising to 320 MW. Heat rating: 530 MW.
FUEL:	Natural uranium. U as rods 1.15 in. dia., 24 in. long. Weight of U per rod: 7.64 kg (16.8 lb). Weight of U per reactor: 51 tonnes. Elements in vertical channels: 10 per channel. Number of fuel element channels: 3288.
CANNING:	Magnesium alloy, Magnox A12. Method of support: graphite sleeves loaded with the cartridge.
MODERATOR:	Graphite. Core size: 44 ft. 6 in. dia., 23 ft. high. Overall size including reflector: 50 ft. 6 in. dia., 28 ft. high. Total weight per reactor: 2,150 tons. Graphite support: 4 in. steel plate on steel grid.
LATTICE:	Regular square, 8$\frac{1}{4}$ in. pitch.
PRESSURE VESSEL:	Coltuf 28. Shape and dimensions: 70 ft. i.d. sphere. Thickness: 2$\frac{7}{8}$ in., support course, 3 in. Maximum internal working pressure: 150 p.s.i.g. Weight of gas in vessel under operating conditions: 41.4 tons. Maximum shell temperature: 450° F. Inner shell: boiler plate, cylindrical sides, domed top.
COOLANT:	Carbon dioxide. Inlet temperature: 204° C. (400° F.). Outlet temperature: 396° C. (745° F.). Inlet pressure: 150 p.s.i.g. Outlet pressure: 145.8 p.s.i.g. Mean fuel rating: 2.11 MW/tonne. Flow: 5,640 lb/sec. Heat transferred to gas from reactor: 530 MW. Heat transferred from gas in heat exchangers: 540 MW. Number of ducts: 8 inlet, 8 outlet per reactor. Duct diameter: 5 ft. Gas transit time round circuit: 23 sec.



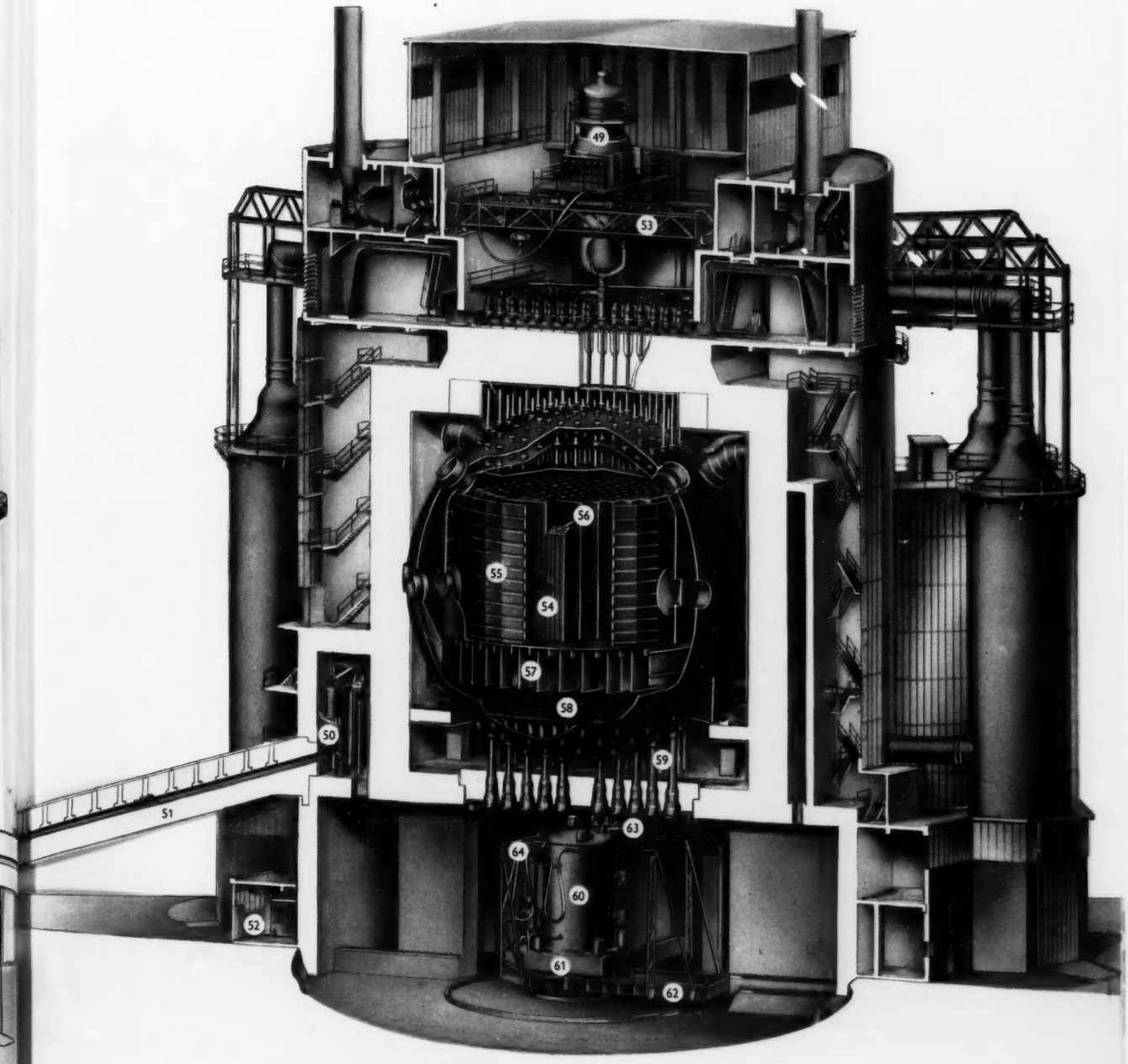
1. Reactor building
2. Steam raising unit pressure vessel
3. Steam raising unit sub-structure
4. Inner concrete shield
5. Outer concrete shield
6. Duct chamber
7. Charge chamber
8. Hot gas duct nozzle
9. Cool gas duct nozzle
10. Control rod standpipes
11. Control rod mechanisms
12. B.S.D. precipitator room
13. Thermal column
14. Pressure vessel support columns
15. Main reactor support columns
16. Gas circulator motor



17. B.S.D. control apparatus
18. Control rod motor supply units
19. Switchgear
20. Ion chamber room
21. Charge-discharge control room
22. Charge preparation room
23. Compressor room
24. Spherical pressure vessel
25. Hot gas duct
26. Cool gas duct
27. Gas valves
28. Bellows joints
29. Boiler drums
30. Boiler circulating pumps
31. Steam raising unit tube banks
32. Gas circulator impeller



33. Exhaust fan and chamber
34. Duct support structure
35. B.S.D. precipitators
36. Charge machine test shaft
37. Charge machine test bay
38. Grid support ring
39. Cooling air supply duct
40. B.S.D. cooler
41. Inner steel shell
42. Stiffening rings
43. Pressure vessel interior
44. Steel supporting skirt
45. Upper concrete shield
46. Lower concrete shield
47. Inner shield plate
48. Shield cooling ducts



49. Reactor servicing machine
50. Spent fuel separating room
51. Spent fuel conveyor
52. Separating control room
53. Servicing machine gantry
54. Reactor core
55. Core restraints
56. Fuel channel
57. Grid
58. Collector pan
59. Charge-discharge standpipes
60. Charge-discharge machine
61. Charge machine carriage
62. Charge machine turntable
63. Charge machine nozzle
64. Charge machine supplies

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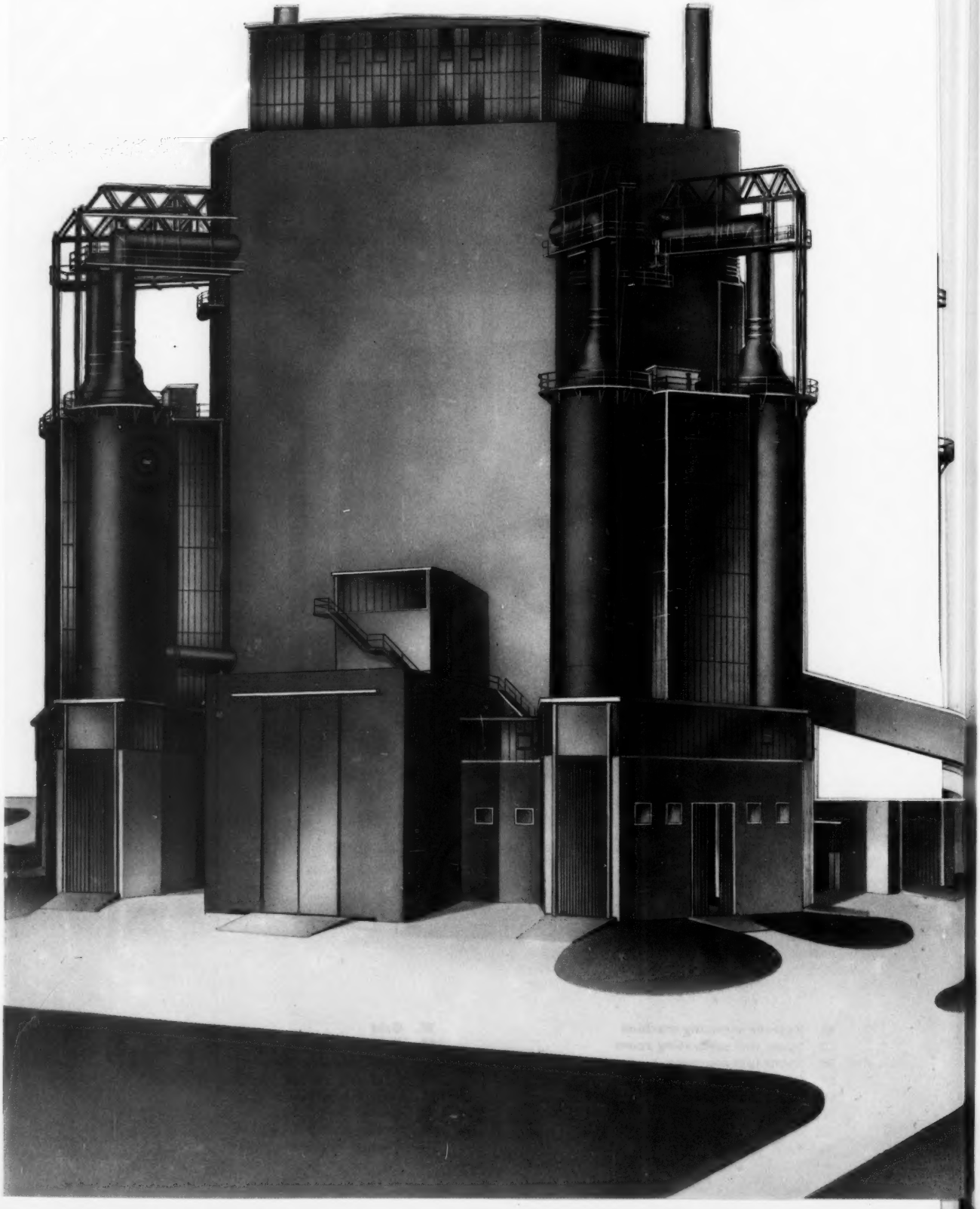


Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. BEPO (April, 1956)
No. 2. CP5 (May, 1956)
No. 3. NRX (June, 1956)
No. 4. DIMPLE (August, 1956)
No. 5. ZEUS (September, 1956)
No. 6. CALDER HALL (October and December, 1956)
No. 7. Russian 5 MW (November, 1956)
No. 8. DIDO (January, 1957)

PUMPING:
Eight vertical shaft, centrifugal blowers per reactor.
Drive: d.c. motors supplied from grid controlled rectifiers.
Outlet gas pressure: 150.5 p.s.i.g.
Gas pressure rise across circulator: 7.5 p.s.i. max.
Circulator input: 2,190 b.h.p.
Electrical power consumption per reactor: 12.6 MW.
Running speed: 1,000 r.p.m.
Speed control: Grid controlled mercury arc rectifier: 10:1.

FLUX:
Maximum thermal neutron flux: $2 \times 10^{13} n/cm^2$-sec.
Method of flattening: steel bars replacing fuel elements.

CONVERSION:
Average initial conversion factor: 0.800.

BURN-UP:
2,500 MWD/tonne.

REACTIVITY:
Excess reactivity: 4.5% in k at start-up.

CONTROL:
Number of channels: 208 per reactor.
Diameter of channels: 3.5 in.
Rod-construction: Boron-containing inserts canned in thin stainless steel sheet and packed in stainless steel tubes.
Dimensions of rod: length 21 ft., diameter 2 in., weight 70 lb.

HEAT EXCHANGERS:
Number per reactor: Eight.
Total gas volume: 18,000 cu. ft. per unit.
Total wt. of gas under operating conditions: 5.2 tons per unit.
Inlet temperature: 396° C. (745° F.).
Outlet temperature: 200° C. (392° F.).
H.P. steam flow: 143.1 klb/hr. per heat exchanger.
H.P. steam pressure: 575 p.s.i.g.
H.P. steam temperature: 700° F.
L.P. steam flow: 69.5 klb/hr. per heat exchanger.
L.P. steam pressure: 145 p.s.i.g.
L.P. steam temperature: 670° F.

TURBO-GENERATORS:
Number of sets per station: six multi-stage, axial flow, impulse-reaction.
Continuous maximum rating per set: 60 MW.
Cooling: hydrogen at 30 p.s.i.g.
Speed: 3,000 r.p.m.
Generator voltage: 11.8 kV.
Power factor at C.M.R.: 0.8.
Steam pressure at H.P. stop valves: 555 p.s.i.g.
Steam pressure at L.P. stop valves: 135 p.s.i.g.
Steam temperature at H.P. stop valves: 690° F.
Steam temperature at L.P. stop valves: 660° F.
H.P. steam flow per set: 382 klb/hr.
L.P. steam flow per set: 186 klb/hr.
Final feed temperature at C.M.R.: 296° F.

STEAM DUMPING:
Two condensers per station, operating at atmospheric pressure, with spray de-superheaters. Steam released to dump through automatic pressure controlled valves.

The G.E.C.—Simon Carves Design

The South of Scotland Electricity Board are to place a contract with the G.E.C.-Simon Carves Atomic Energy Group for the construction of a 300 MW station. The departures in design from the Calder Hall prototype are examined, the major differences being concerned with increased size and charge and discharge on load from the underside.

THE reactor core which with its graphite reflector is 50 ft. 6 in. diameter and 28 ft. high is pierced by 3,288 channels for fuel elements and 208 holes for control rods. The pile made up of interlocking blocks of graphite is supported on steel plates resting on a heavy grid structure which in turn is supported by a skirt welded to the main pressure vessel. The pressure vessel itself is spherical of 70 ft. internal diameter and is supported on a cylindrical skirt welded to the vessel exactly opposite the grid support. Inside the main pressure vessel and surrounding the core is a cylindrical inner vessel with a domed top. The whole structure is supported on radial concrete walls which in turn rest on a circular concrete raft with additional thickness immediately under the reactor.

Charge and discharge of the fuel elements which are individually supported in graphite sleeves is from the bottom through 101 charge tubes, each central tube serving 36 fuel channels. The charge and discharge operation is integral in one machine and the operation can be carried out with the reactor on load. Normal fuel cycling can be carried out by the machine in one shift daily. The control rods enter the reactor from the top, 208 stand pipes being provided, most of which are occupied by the control rods and mechanisms. On the control face a reactor servicing machine is mounted to undertake planned maintenance of the control rod mechanisms and for general inspection and manipulation within the reactor. The main biological shield is of reinforced concrete 9 ft. thickness on the sides and 10 ft. 6 in. on the top. The shield is split in the region of each gas duct to minimise streaming and to shield the hot gas during the first part of its cycle. Whilst no thermal shield is included, immediately over the reactor core cladded boron steel plate reduces the upward neutron flux and similar plates opposite the outlet ducts further cut down streaming.

The ducts are 5 ft. in diameter; one inlet and one outlet is provided for each of the 8 steam raising units. The steam raising units are 70 ft. in height and 20 ft. in diameter and are mounted symmetrically around the reactor and are designed for outside operation, but for amenity reasons may be enclosed in a building. The CO_2 circulators are integral with the bottom of each heat exchanger and consist of centrifugal blowers powered by a d.c. motor fed through mercury arc rectifiers. Thermal expansion in the ducts is taken up in hinged bellows.

Pressure Vessel

Economic power calls for large reactor cores because the capital cost per kW decreases with increasing output. This increase in thermal output is obtained not only by a volumetric increase of the reacting core, but also due to better neutron distribution by the degree of flattening and hence greater heat rating for the outer channels than is possible at, say, Calder Hall. The limit to the size of the core is governed by the need to cater for differential thermal expansions in the supports of the core and similar engineering considerations rather than by nuclear physics or fabrication limitations. It was considered that in view of the improvement in site welding techniques that 3 in. plate could be welded to the exacting standards necessary, and as a result of the experience of Motherwell Bridge and Engineering Co. on the construction of spherical vessels for Dounreay and for refinery work, it was felt that a spherical vessel was a better proposition as regards layout, design and construction than a cylindrical vessel. When considering the materials from which the pressure vessel should be constructed it was concluded that no steel could be found which would combine the desirable features of high notch ductility with good creep strength at high temperature and easy weldability. As a result it was decided to have a double shell, the outer of which would be a pressure vessel but would be maintained at a temperature below the creep region by allowing a bleed of the incoming cool gas to flow over the wall without passing through the reactor. The maximum temperature of the outer shell has been set at 250°C and Coltuf 28 has been chosen as the most suitable material. Coltuf 28 is a steel that is readily weldable and has a low ductile/brittle transition temperature. The inner shell which confines the reactor and which will attain temperatures comparable with the maximum temperature of the fuel channels is to be constructed of boiler plate. The thickness of this is $1\frac{1}{2}$ in. whereas the pressure vessel is of $2\frac{7}{8}$ in. increasing to 3 in. in the region of the skirt.

Skirt Support

Consideration was given to the two main types of support used in current practice, viz. individual rolling supports as represented by the A-frames on the Calder Hall reactors and a continuous edge support. It was considered that the stresses set up in the pressure vessel due to point support would be greater than those encountered in the skirt type, provided that the outer skirt supporting the vessel and the ring supporting the steel grid were properly designed. Whilst the A-frame system is satisfactory provided all frames are exerting equal thrust, errors in fabrication or differential expansions in the pressure vessel are liable to produce unequal thrusts, the effects of which are difficult to calculate.

Bottom Charging

The most striking divergence from existing practice is the provision for integrating the functions of charge and discharge into one machine and operating the machine from beneath the reactor. A number of advantages of this method are immediately obvious. The machine, which for a power reactor is required to operate on load, is located at the cooler side of the system and the function of charge and discharge and control are separated. This allows greater freedom of operation both in the charge and discharge itself and also in the arrangement of the control systems and in the provision for maintenance of the control rod mechanisms.

With the additional space available, the layout of the burst-slug detection and ancillary gear has been considerably eased. Another important result of separating the control rods from the charge and discharge is that, during charge and discharge operations, the control-rod system can be fully operative with all rods available for taking up changes in reactivity.

As the fuel cartridges are individually mounted within graphite sleeves, a complete channel can be discharged at one operation. Also, in the charge machine provision is made for the dividing of a single stack of elements into two and replacing them in the opposite order. With the degree of flattening obtainable in the reactor, radial cycling is not economical. Axial cycling, however, whereby fuel elements in the centre of the reactor are interchanged with those at the top and bottom, should give a considerable increase in the burn-up obtainable. With the system adopted, it is also possible to control the cooling through the empty channel (following discharge) from the charge machine. Without this provision, the change in cooling characteristics of the empty channel would be considerable, but the system allows the temperature of the moderator to be maintained reasonably constant.

The reactor-servicing machine, which is mounted on the control face, can perform a number of valuable functions. An instrument can be passed from the control face through the stand pipes, through the reactor and out of the charge tubes and can, if necessary, operate in the charge machine itself. That is, should a cartridge be jammed, for example, in the charge machine it can be freed and, if necessary, carried away through the top face 135 ft. above. This is an unlikely fault; but one fault that must be guarded against is the possibility of fuel elements jamming in the channel. A CO_2-powered ram can be operated from the servicing machine to force the offending elements downwards into the charge machine. Provision is made for the attachment of thermocouples to some of the fuel cartridges and these will be loaded from the servicing machine. At the completion of their irradiation, the servicing machine will cut the cables and the elements will be discharged downwards in the normal way. The ability to gain access to the pressure vessel and core from both sides is clearly a desirable feature, and it is expected that the use of television will assist not only in the clearing of faults but in the routine examination of components in the reactor. A not insignificant feature also is the considerable reduction in the possibility of having active material on the control floor.

The machine's control gear and the control console are mounted on the crab of the machine, the operator being provided with local shielding. Use is made of closed-circuit television to supervise the various operations.

Problems of support introduced by the need for access below the reactor are not entirely disadvantageous in that the radial system of walls supporting the reactor and biological shield assists in distributing the weight over the raft. The total weight of the structure and the total height are, of course, correspondingly increased, but it is felt that these are minor objections compared with the advantages just discussed.

Fuel Elements

Whilst the general form of the fuel elements is similar to those used in Calder Hall, the length has been reduced to 24 in. and provision has been made for their individual support inside graphite sleeves. These sleeves are not a tight fit in the channels in the moderator, a $\frac{3}{16}$ in. radial gap having been left to provide cooling of the moderator. One of the main factors affecting fuel-element life is liable to be creep in the can, but if the life is kept comparable with that obtainable at Calder Hall a higher operating temperature can be used. Apart from creep of the fins, which will affect their heat-transfer characteristics, long fuel elements carrying loads are liable to bowing which can cause problems in heat transfer or even more serious problems with burst cans. The ability to cool the moderator independently of the fuel elements is also an advantage with large cores. As discussed previously, the individual support and the ability to discharge in one operation complete channels facilitates considerably axial cycling of the fuel. The individual stacks of elements and the main graphite structure are not mounted on roller bearings as at Calder Hall, the bottom layers being keyed into the steel supporting plates. Special interlocks between successive rows of graphite blocks allow the vertical columns of graphite to move with the steel as it increases its dimensions with temperature, whilst at the same time retaining the essential symmetric configuration with smooth and continuous channel walls.

Gas Circuits

As with the reactor itself, it is considered more economical to build large steam-raising units rather than divide the operations into a number of smaller units. Above a certain size, however, problems arise with the erection of these vessels, and whilst the individual vessels are a small increase on those used at Calder Hall the greatly increased capacity is achieved by doubling the number to eight. Each vessel is self-supporting and stands on a cylindrical support and base ring. The elements are supported within the vessel only at their ends in order to keep the holding structure out of the gas stream, the individual tubes being tied together by welded straps to give rigidity to the element. It has also been considered advisable to retain the system of single inlet and outlet ducts, these being increased to a size of 5 ft. General arrangements for the supports and expansion joints are similar to those adopted at Calder Hall but, by ensuring that the duct system is entirely in one plane, it has been possible to dispense with gimballed joints and use hinged bellows only.

At the pressure differences involved, the efficiencies of axial and centrifugal blowers are not very different and, whilst centrifugal blowers have the advantage of simpler impeller construction, the normal disadvantage of casing construction has been eliminated by installing blowers in the bottom of the heat exchangers.

The drive for the blowers requires a difficult compromise between pumping efficiency, large speed range and reliability of operation. It would appear that there is no best system of combining these characteristics, and the company has concluded that its optimum approach is through a system of which it has considerable experience. With the company's background of work on d.c. motors and grid-controlled mercury arc rectifiers, it has adopted this system of drive and control. A number of seals have been under investigation and final decisions on the types adopted will not be made until the last possible moment, so that the maximum time can be spent on testing. The system of mounting the blowers in the bottom of the heat exchangers with the motors slung below allows a clean design with good access for maintenance of the motors and seals. It also permits minimum routeings for the cold gas duct.

Maintenance

As discussed above, the separation of the charge and discharge operations from control-rod operation permits remotely-controlled access into and through the core. The

reactor-servicing machine is provided with a number of manipulative and inspection devices to allow reactor examination of the interior and the pressure vessel. Should unexpected faults develop such as occurred at Windscale, adaptations of this machine could be used for carrying out limited repairs. The pressure vessel itself will be comprehensively provided with strain gauges for the measurement of displacements, creep and stresses, and other inaccessible sections will also be liberally instrumented. A personnel access hole is provided in the main biological shield, but it is not envisaged that once the reactor has been in operation for some time that this would ever be used. However, it was considered desirable to provide such access to allow for changes in maintenance technology and safety philosophy. The gas circuits for the most part will be accessible through manholes, the activity in these sections dying off fairly rapidly after shut-down. Other active components, such as the charge and discharge machine, are designed to be amenable to a reasonably conventional maintenance approach.

Reactor Rating

A critical feature of the maximum rating of the reactor is the maximum temperature permissible in the fuel cartridges. The system of individual support minimizes the limitations imposed by creep, but phase changes in the uranium caused by minor excursions in temperature and the low melting point of magnesium will not allow a very great increase over that used at Calder Hall. As a result, the ratings of the rest of the reactor system are not a limiting feature. Some consideration must be given to the replacement at a future date of the magnesium-covered fuel elements by beryllium cans, at which point the operational temperature may be governed by components external to the core, such as the pressure vessel. The double pressure vessel itself, however, protects the main pressure container from the effects of creep at higher temperatures by permitting the outer shell to be maintained at a relatively low temperature and it is probable that the graphite support structure will become the most critical part of the system. With the size of core used, changes in dimension with temperature are considerable and, whilst this is at the cool end of the circuit, it must accommodate the dimensional changes in the moderator itself. At higher temperatures, also, differential thermal expansion associated with the stand pipes will not be insignificant. In any case, the efficiency of the system at present envisaged will allow economic operation of the first power station (at least) at the design conditions, and it may well be felt advisable never to exceed these design conditions during the life of the reactor.

Operation and Control of the S.S.E.B. Station

Details are given of the fuel element charge and discharge operations, unloading of spent fuel into the cartridge-cooling ponds and burst-slug detection. The control-rod system is dealt with, together with overall station control and instrumentation.

To increase the total heat output of the reactor without overheating the central fuel channels, the neutron flux distribution is flattened by inserting stainless-steel rods into a number of the central core channels. As the fuel is burned up during operation, these rods are gradually removed and the flattening is finally achieved by axial inversion of partially irradiated fuel elements, whereby those elements originally placed in the centre of the channel are re-positioned at the ends.

In the outer region of the core the moderator channel is reduced in diameter by increasing the thickness of the graphite sleeves containing the fuel elements. This decreases the mass flow of CO_2 up the channel, thus keeping up the temperature of the fuel can and thus of the outlet gas. Gas temperatures from all parts of the core are therefore kept fairly uniformly alike. Control of the gas temperature is achieved by restricting the flow through some of the fuel channels outside the flattened region by means of steel plates with central holes of varying diameter. The gas temperature to the heat exchangers can be maintained approximately constant at 745°F.

The gas flow through the system is 5,640 lb./sec., the gas being circulated by centrifugal blowers, one being located in the base of each heat exchanger so that it handles the gas at the lowest temperature (400°F). To counteract pressure losses in the system, the circulators have to develop a pressure rise of 7.5 p.s.i. maximum. The circulator drive is by a tandem-armature d.c. shunt motor rated at 2,200 h.p. at 1,000 r.p.m. supplied through transformers and 12-phase steel tank mercury-arc rectifiers having grid control by individual phase shifters. The shaft seal will be either of the rubbing-face or viscous-oil type. The motor and drive unit can be detached and replaced by a spare unit, should lengthy maintenance work be necessary.

In the event of the failure of a circulator or any component, rapid-closing isolating valves at the reactor inlets and outlets ensure quick isolation, reduced reactor load then being carried by the units remaining in service.

The steam-raising plant consists, in principle, of two water-tube boilers—one high pressure, the other low pressure. Because of the relatively low gas temperature difference the area of heat exchange surface must be large, and close-pitched small-diameter tubes with finned extended surfaces have been adopted. In the evaporator and economizer banks, the fin will be a mild-steel spiral wound on to, and continuously welded to, the tube. The superheater tubes will have simply two longitudinal strip fins welded on.

The turbines follow the general lines of the conventional G.E.C. 60-MW dual-pressure units incorporating certain design features of the latest 120-MW and 200-MW reheat turbines: the most important of these is the use of fabricated steel exhaust casings with end support only, the longitudinal girders being formed integral with the casing walls. The steam at exhaust has a wetness of about 12.5% for 28.9 in. Hg vacuum at design load. It is economic to provide a generous exhaust area, as a high leaving loss would markedly reduce the effective output, taking into account the low steam inlet conditions.

Charge and Discharge

The entire fuel charge and discharge operations for each reactor are carried out by a single multi-purpose machine working in a shielded chamber below the reactor. All operations can be carried out under pressure and while the reactor is on load.

The 3,288 fuel channels, in charge groups of 36 channels each, are continued downwards through the grid by fixed channel tubes. In any one charge group, the fixed channel tubes are bent inwards into gentle curves so that their open lower ends can be fed from a point below the centre of the group. Vertically below this centre line is a standpipe for each charge group—101 in all. Thus through each of these 101 standpipes any one of 36 fuel channels in a charge group can be reached by the charge machine.

The charge machine vessel is approximately cylindrical, 30 ft. high, and capable of withstanding the full gas operating pressure. It is seated in a carriage mounted on four wheels. The carriage wheels run on tracks which are, in turn, mounted on a turn-table spanning the diameter of the charging chamber. The turn-table runs on two concentric sets of tracks and can rotate through 360°. Thus, by rotation of the turn-table and movement of the carriage along it, the nozzle in the top of the charge machine can be aligned directly beneath any chosen standpipe.

From the charge-preparation room above the loading bay, five fuel elements, together with a support device and empty graphite tube, are lowered into one tube of a "magazine tube pair" which consists of a long open-ended cylinder of polished stainless steel. The empty graphite tube ensures that the lowest fuel element is in the moderator section of the core and not in the surrounding reflector area below. Five more elements are then lowered into another similar tube, the two being strapped together and forming a "magazine tube pair" containing a complete fuel element charge for one channel. The pair of tubes is then guided downwards through a hatch in the charge-preparation room floor into the opening in the top of the charge machine.

This process can be repeated if necessary until several pairs of tubes are supported in racks within the machine. The magazine itself is shielded by a 1 ft. thickness of lead. The loaded machine is driven back on to the turn-table and the nozzle positioned below the required standpipe.

Precise alignment to within 1/10 in. is effected with the aid of two television cameras mounted at right angles on top of the charge machine. The cameras are focused on vertical datum lines on the standpipe and the charge machine nozzle, and the position of the machine is adjusted until these coincide on the television monitors in the control room.

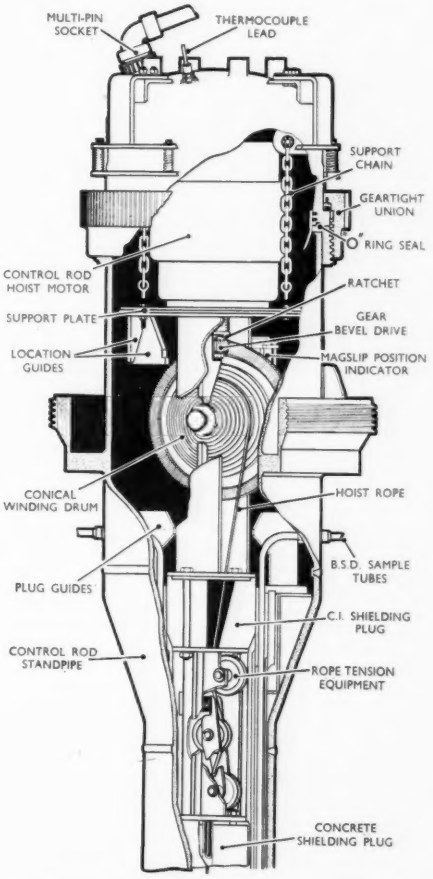
Clearance between the top of the machine nozzle and the bottom of the standpipes is about 3 in. This clearance is taken up by raising the whole machine on four synchronized electrically-operated jacks until the surfaces abut. The flanges on the two nozzles are then clamped together over an "O" ring by eight CO_2-operated piston clamps situated radially round the nozzle.

Discharged radioactive fuel elements are retained within the machine during the recharging process and are later removed for separation of the graphite sleeves from the fuel cartridges, the latter being stored in the cooling pond.

It is intended that once a day the charge machine should be run into a test bay to undergo a series of tests corresponding exactly to the handling of fuel in the reactor, in order to prove that the machine is in proper working order. The test bay is provided with a dummy standpipe end and above it a group of 36 dummy fixed channel tubes at a level corresponding to that inside the reactor.

The cartridge-cooling pond is situated between the two reactors and is common to both of them. It is 186 ft. long by 53 ft. wide internally, with a depth of 18 ft. At the termination of each conveyor duct there is a heavily shielded concrete block-house, and between the two block-houses on opposite sides of the pond is a concrete wall. The pond is thus divided into two unequal sections, the larger for storing normal discharged cartridges and the smaller for cartridges from channels in which a burst has occurred.

The boat carrying a cartridge down the chute is tilted



Motorized operating head for a control rod. The rod is moved by altering the frequency of the L.F. supply to the motor.

at the end of its travel, tipping the cartridge into a hopper. The hopper, controlled from the separating room, can then be rocked to either side, causing the cartridge to roll down a chute leading either to the "clean" or "dirty" section of the pond, where it comes to rest under water visible to the pond operator.

The pond operator picks up the cartridge with a simple mechanical manipulator and places it in a storage skip. Inside the skip is a grid rack in which up to 192 cartridges can be stored vertically. When the skip has been filled, it is picked up by the pond transporter crane and carried under water to a predetermined position in the pond, where it will remain for 120 days. During this period gamma activity decreases to a level at which a reasonable thickness of shielding, say about 1 ft. of iron, can be used for the transport coffin.

The capacity of the cooling pond is such that the complete fuel charge from one reactor can be dumped within it in the event of an emergency, as well as the normal number of cartridges issuing from one runnning reactor.

At the end of their storage period in the pond the skips are reclaimed by the pond transporter and placed in the transport coffins in which they will be removed from the site. The coffins are lowered into the pond by overhead gantries, one of which is sited at each end of the pond. The coffin lids are removed under water by the pond transporter, the skip lowered into the coffin and the lid replaced. The loaded coffin is lifted out by the gantry, washed down, placed on the transport vehicle, and removed for reprocessing by the U.K.A.E.A.

Control Rods

There are 208 control channels, of which 150 will contain control rods. Details of the rods are given on page 53. The control-rod mechanism consists of a flexible, multi-strand, stainless-steel wire wound on to a conical drum driven by a low-frequency permanent magnet motor, the cable winding from the smallest diameter to the largest as the rod is raised. The control rod is raised or lowered by applying a three-phase L.F. supply to the motor stator, the rods being held stationary by reducing the frequency of the supply to zero, thus in effect freezing the three phase. The L.F. supply is obtained from a motorized induction regulator uniquely connected with transformers and rectifiers, the equipment being situated outside the biological shield. The control-rod motors are arranged in four groups, each group being coupled to the same L.F. supply, and the motors therein are thus driven in synchronism. A second winding, of the closed-cage, high-resistance type, is incorporated in the stator to assist in controlling the rate of descent of the control rod on shut-down. The motor is silicone and glass insulated with glass-to-metal seals for the multi-pin socket. With the winding gear it is held in the channel head by a geartight ring, facilitating easy removal of the operating mechanism.

In the event of an emergency, all motor stators are de-energized simultaneously by cutting off the power supply. The rods fall into the core under gravity, accelerating until they are well into the core, when a braking force is applied towards the end of their travel. This is governed by the conical shape of the winding drum and the impedance of the closed winding in the stator. A broaching mechanism is embodied in the head of the rod. During operation the position of each control rod is detected by a magslip coupled to the winding drum. Slack or overtaut rope detection is also incorporated.

The coarse group has slow-in and slow-out times of 8 hr., and a fast-in of 12 min. The safety rod groups have in and out times of 2 hr., whilst fine control is dealt with by the automatic power control system, discussed later.

Burst-slug Detection

The tracing of faulty fuel elements is performed by successive sampling, in groups of four, of the gas from the 3,288 fuel element channels throughout the reactor. Any solid components in the gas are filtered out and the daughter products of gaseous fission products are electrostatically precipitated to give a measure of the extent of a fault in an element. Each filter unit contains a Geiger counter to detect any deposits of uranium oxide. The precipitators are located in two diametrically opposite rooms on the reactor cap.

When the sample test shows a high activity level in a group of four channels, it is possible to operate the B.S.D. equipment so that the individual faulty channel in the group may be located. The B.S.D. equipment has been designed for maximum reliability, yet is flexible enough to be modified for changed operational requirements. Selection of channels is by means of two sets of rotating, graphite-lubricated valves, mounted outside the reactor for ease of maintenance.

A permanent record of each sampling operation is automatically charted and a comprehensive system of alarms indicates to the control engineer in the central control room not only a burst slug but also any fault in the equipment itself. Automatic operation reduces to a minimum the time taken for a complete reactor scan, and additional equipment provides for the frequent sampling of a suspected channel without lengthening unduly the time between samples of any other channel.

Control and Instrumentation

A comprehensive system of manual controls and appropriate instrumentation for the two reactors and their associated plant is provided in a central control room situated in the turbine building. This, in conjunction with an extensive telephone system, both normal and emergency, ensures complete control over the reactors and steam-raising units under normal and all except certain extreme emergency conditions; adequate control over all other significant items of plant is vested in the central control room. A turbine gauge panel is placed in close proximity to each turbine, and instrumentation is included in the central control room to afford supervision of the running turbines.

Certain automatic features are incorporated in the control system of each reactor unit. These simplify the adjustment of power level and perform stabilizing functions; manual override is provided. Expressed in its

La Centrale d'Energie Nucléaire de l'Ecosse du Sud

La Régie de l'Electricité du Sud de l'Ecosse a annoncé qu'elle a l'intention de passer un contrat au G.E.C. Simon-Carves Atomic Energy Group pour la construction d'une centrale d'énergie nucléaire. Cette centrale sera construite dans le sud de l'Ecosse et on s'attend à ce qu'elle soit prête pour les essais de mise en opération vers la fin de 1960.

La centrale, qui est basée sur le prototype de Calder Hall, comprend deux réacteurs, alimentant chacun trois groupes turbo-alternateurs. Le rendement électrique net est évalué à 300 *MW, s'élevant à* 320 *MW pour une chaleur nominale de* 530 *MW par réacteur. Chaque noyau de réaction est monté dans un bac à pression sphérique qui est soutenu par une chemise transmettant la pression le long du système vers une série de murs en béton en étoile. Le noyau est percé de* 3.288 *canaux, chacun d'eux pouvant recevoir* 10 *cartouches de combustible de* 61 *cm. de long, supportées individuellement dans des manchons de graphite. On accède aux canalisations de combustible par des tubes de chargement au bas du réacteur, tandis que des tiges de contrôle pour lesquelles* 208 *canaux sont prévus sont actionnées par des tuyaux montants à la partie supérieure du réacteur. Une machine permanente d'entretien de réacteur effectue un entretien des mécanismes des tiges de contrôle selon un programme préconçu, ainsi qu'une inspection régulière de l'intérieur du réacteur, et elle peut être employée pour une manipulation limitée en dedans du noyau du réacteur, comme par exemple pour le dégagement d'éléments combustibles coincés.*

Chaque réacteur est pourvu de 8 *groupes producteurs de vapeur qui actionnent un cycle de vapeur à double pression. Ils sont montés à l'extérieur du bâtiment du réacteur mais peuvent être renfermés pour plus de commodité.*

simplest form, the method of overall control between 25% and 100% full power involves co-ordinated variation of the neutron flux density, the coolant gas flow and the steam flow. Two separate closed-loop circuits are incorporated, one for stabilization of reactor power operating on four fine control rods, and the other for stabilization of the total coolant gas flow operating on the circulators. These are termed respectively the automatic flux regulator and the automatic flow regulator. The two circuits are combined to the extent that settings of desired neutron flux and desired coolant flow are coupled in a single control known as the automatic power control, which is motorized (to limit the rate of change of power) and set by the reactor operator at his control desk. A constant ratio is maintained between desired neutron flux and desired coolant gas flow (subject to manual trim). With this system, there is only a small variation with power level of temperatures in the coolant circuits.

The automatic flux regulator adjusts reactivity to compensate for xenon poison transients following deliberate changes in power level, and also maintains a stable power level during "on-load" maintenance operations, such as replacement of control rods, which affect the net reactivity.

The automatic flow regulator maintains the desired value of total coolant flow in the event of failure of one circulator by temporarily overspeeding the other circulators.

When the operator adjusts the desired power by means of the automatic power control, the resultant changed flow of coolant results in a change in heat flow in the steam-raising units. Steam pressures are thus affected, and pressure regulators associated with the inlet valves to each turbine automatically adjust the steam flow to maintain constant pressure conditions. Each steam-raising unit has a simple form of automatic feed-water control operating from drum level.

It is estimated that a power reduction from 100% to 33⅓% full power is capable of being almost entirely carried out in a controlled manner in under 30 minutes by means of the automatic features provided. As excess steam is blown off in the event of one or more turbo-generators tripping out, rapid decrease of power without having recourse to reactor shut-down is obviously desirable to avoid excessive loss of feed-water.

An unsafe condition is arranged to trip out automatically a section or sections of the station. As this must be done as a last resort, particularly where the reactor is involved, the equipment associated with each of these trips is made as reliable as possible, the more particularly because should it develop an internal fault it must "fail safe". To reduce the risk of trips due to internal equipment faults in the particular case of excess neutron flux detection, three detectors are employed, any two of which must operate before the reactor is tripped.

The instrumentation installed: (1) detects and displays to the control staff any departure from normal of the significant parameters and controls under all conditions of operation; (2) actuates alarms, auto-regulation and auto-trip-out of sections of the station; (3) enables changes in the operating power level, start-up and shut-down of any section of the plant to be performed smoothly and promptly, whether by manual or auto-control or by a combination of the two, and prevents or minimizes the effect of maloperation of controls; (4) provides an easily interpreted record of any measurement of which it is important to know the trend with time; (5) enables a variety of remotely-controlled maintenance operations to be performed on the reactor.

Das Werk der Elektrizitäts
Behörde in Süd—Schottland

Die Elektrizitäts Behörde von Süd Schottland hat mitgeteilt, dass die Absicht besteht, einen Kontrakt mit der G.E.C. Simon-Carves Atomic Energy Gruppe abzuschliessen, der die Konstruktion eines Atom Kraftwerks zum Gegenstand hat. Das Werk wird in Süd Schottland errichtet werden, und man erwartet, dass der Bau Ende 1960 *soweit gediehen sein wird, dass Versuchs-Läufe in Auftrag gegeben werden können.*

Das Werk, das dem Vorbild des Calder Hall Werks entsprechend gebaut wird, besteht aus zwei Reaktoren, die jeder drei Turbinen Sätze für Wechselstrom-Generatoren speisen. Die elektrische Netto Leistung ist auf 300 *MW festgesetzt, die auf* 320 *MW ansteigen kann bei einer Wärmeerzeugung von* 530 *MW je Reaktor. Der Kern eines jeden Reaktors ist in einem kugelförmigen Hochdruck-Behälter montiert, der auf einem Ring sitzt, durch den die Last auf eine Reihe radial angeordneter Beton Mauern übertragen wird. Der Kern wird von* 3.288 *Kanälen durchschnitten, von denen jeder* 10 *Brennstoff Patronen aufnehmen kann, die* 24 *Zoll lang sind und einzeln in Graphit Hülsen sitzen. Die Brennstoff Kanäle sind durch Füllrohre zugänglich, die am Boden des Reaktors angeordnet sind, während die Regulierungs-Stäbe, für die* 208 *Kanäle vorgesehen sind, durch Standrohre über dem Reaktor betrieben werden. Eine ständig zum Reaktor gehörende Instandhaltungs-Maschinerie dient zur plangemässen Unterhaltung des Mechanismus für die Regulierungs-Stäbe und zur regelmässigen Beaufsichtigung des Inneren des Reaktors und kann begrenzt auch für Manipulationen innerhalb des Reaktor-Kerns benutzt werden, wie zum Beispiel für die Freimachung von verklemmten Brennstoff Patronen.*

Jeder Reaktor ist mit 8 *Dampf erzeugenden Einheiten versehen, die jede mit einem zweifachen Druck-Kreis arbeiten.*

La Central de Energía Nuclear
del Sur de Escocia

La Administración de Electricidad del Sur de Escocia ha anunciado que tienen la intención de celebrar un contrato con el Grupo de Energía Atómica G.E.C. Simon-Carves para la construcción de una central de fuerza nuclear. Esta central será construída en el Sur de Escocia y se espera que esté lista para sus pruebas finales hacia fines de 1960.

Basada en el prototipo de Calder Hall, esta Central incluye dos reactores, cada uno alimentando tres grupos turbo-alternadores. El rendimiento neto en electricidad se calcula en 300 *MW elevándose a* 320 *MW por un régimen de calor de* 530 *MW por reactor. Cada núcleo reactor va montado en un recipiente esférico de presión, el que es soportado sobre un faldón transmitiendo el empuje a través de una serie de muros de betón radiales. El nucleo es agujereado por* 3.288 *canales, cada uno de los cuales puede alojar* 10 *cartuchos de combustible, de* 24 *pulgadas* (61 *cm.*) *de largo, individualmente soportados en manguitos de grafito. El acceso a los canales de combustible es a través de tubos de carga en el fondo del reactor, mientras que las varillas de control, para las cuales se proveen* 208 *canales, se operan a traves de tubos montantes en la parte superior del reactor. Una máquina de mantenimiento permanente del reactor lleva a cabo un mantenimiento planeado de los mecanismos de las varillas de control y una inspección regular del interior del reactor y puede ser usada para manipulación limitada dentro del núcleo del reactor, como por ejemplo, la liberación, de elementos de combustible atascados.*

Cada reactor se halla provisto de 8 *unidades de generar vapor que operan un ciclo de vapor de presión dual. Estas unidades son montadas al exterior del edificio del reactor pero pueden ser encerradas para los objetos de la comodidad.*

Power From Thermonuclear Reactions

by

J. G. LINHART, Dipl.Ing., Ph.D.

An analogy is made between the problems associated with the ignition, maintenance and energy extraction from a chemical flame and those of a thermonuclear flame. Calculations are made of the main conditions that must be satisfied when considering the construction of a fusion reactor.

AT the present time an overwhelming majority of nuclear engineers are concerned with problems of power generation based on the nuclear fission of uranium, thorium and plutonium. Although most engineers are aware of the existence of thermonuclear reactions, few would seriously believe that a practicable thermonuclear reactor could be made within their lifetime. Thermonuclear processes are frequently regarded as a rather mythical ocean of energy, whose reserves may be tapped one day in the remote future, but this is a rather pessimistic view. Research on problems associated with thermonuclear reactions has made great progress during the past five years. A large number of reactor mechanisms was originally suggested, but as the relevant concepts of the thermonuclear phenomena have emerged, many of these suggestions have been eliminated.

It now appears that the most fitting basic concept in the study of thermonuclear reactions is the analogy between a nuclear flame and an ordinary chemical flame (Figs. 1a and 1b). It is well known that, in order to ignite a flame based on some exothermic chemical reaction, the igniter must set the reaction going at such a rate that the energy liberated in the reaction outweighs the energy losses from the volume occupied by the flame. The flame then propagates into the combustible mixture until it is active in a volume for which there exists a balance between the energy liberated in reaction and the energy losses.

The rate of reaction in both the chemical flame and the nuclear flame increases rapidly with the temperature and density of the particles entering the reaction. It follows, therefore, that the igniter must be capable of heating a certain minimum volume of the reacting materials to a certain minimum temperature. Thus, for instance, in chemical flames the ignition temperatures are of the order of 1,000°K, whereas the corresponding ignition temperatures for a nuclear flame are of the order of 10^8 ° K. In spite of this large difference in ignition temperatures, the ignition mechanisms in both cases have much in common.

It follows that the subject of thermonuclear research is divided naturally into two component disciplines. The first is concerned with the nuclear reactions and with the manner in which nuclear energy is released. The second discipline is concerned with the kinetic theory of gases as applied to the ignition, maintenance and propagation of the nuclear flame. From an engineering point of view, the subject can be divided roughly into three design projects. First, the design of the igniter; secondly, the design of the nuclear combustion chamber; and, thirdly, the design of the heat-transfer equipment.

In order to appreciate the nature of the task awaiting the engineer in this field, it is necessary to survey briefly the physical background of thermonuclear research. For a more rigorous treatment the reader is referred to the paper by R. F. Post,[1] the relevant chapters in the book by G. Gamow and C. L. Critchfield[2] and the book on fully ionized gases by L. Spitzer.[3]

Fundamental Nuclear Concepts

The atomic nucleus is composed of protons and neutrons which are arranged according to certain rules. The stability of any nuclear structure depends on the value of its binding energy. The binding energy of the nucleus is the energy difference between a system of free nucleons and a system of these nucleons forming an unexcited nucleus.

The total binding energy, W, is derived from the work of several forces. There are the charge-independent forces between adjacent nucleons; these are short-range forces similar to those between molecules in liquids. As the atomic nucleus is not infinitely large, there are always nucleons situated on the surface of the nucleus and these experience an inward force due to the interior nucleons. This force is similar in character to the surface tension in liquids. The coulomb

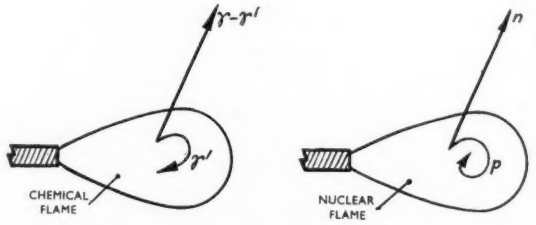


Fig. 1. (a) ordinary chemical flame; (b) nuclear flame.

force of repulsion between the protons within the nucleus is a long-range one and will thus eventually overcome the surface tension forces when the number of protons within the nucleus becomes large. Another nuclear force derives from the short-range interaction between protons and neutrons, and there are several internucleon forces arising from the coupling of orbital and spin magnetic moments.

The work done by all these forces during the assembly of a nucleus, from its constituent particles, is equal to the binding energy, W, of that nucleus. An important concept most frequently used is that of the binding energy per nucleon, $W_n = \frac{W}{A}$. The curve representing this energy, W_n, as a function of the mass number, A, is shown in Fig. 2a.

One of the most general characteristics in the behaviour of complex systems is the tendency towards a structure having

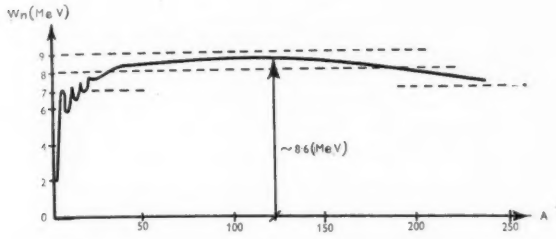


Fig. 2a. Binding energy per nucleon $W_n = f(A)$.

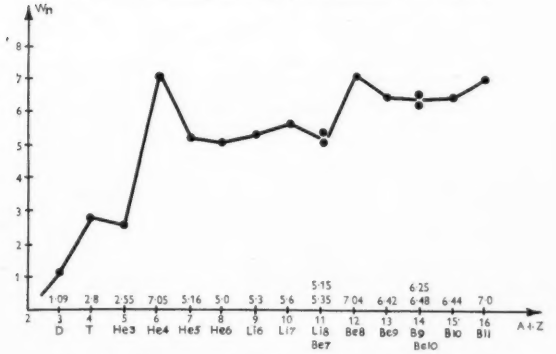


Fig. 2b. Binding energy per nucleon of light nuclei.

a maximum binding energy. This is true of atomic nuclei also, with the result that the products of a nuclear reaction have atomic numbers situated nearer to the peaks of the binding energy curve than the nuclei entering the reaction. Thus, for instance, if a uranium nucleus is involved in a fission reaction it will split into nuclei whose mass numbers correspond to the broad maximum in the neighbourhood of A = 120. It is evident from Fig. 2b that many types of fission reaction are also possible among the light elements, especially in the region:

$$6 < A + Z < 11$$
$$12 < A + Z < 16$$

This tendency to reach a maximum on the binding energy curve is also shown when two light nuclei fuse into a heavier nucleus, the latter having a mass number corresponding to a maximum on the curve. The most typical of these fusion reactions are the following:

$$\left.\begin{array}{l} D+D \longrightarrow T+p\ +4.0\ MeV \\ \qquad\quad \searrow He_3+n\ +3.25\ MeV \end{array}\right\} \text{equally probable}$$

$$T+D = He_4+n\ +17.6\ MeV$$
$$T+T = He_4+2n+11.4\ MeV$$
$$He_3+D = He_4+p\ +18.3\ MeV$$

Reaction cross-section. Those nuclear reactions in which one of the participants is a neutron (particularly the fission reaction) show an increase in the rate of reaction as the speed of the neutron decreases, i.e., the reaction cross-section increases as the energy of the neutron decreases (Fig. 3a). A different situation arises in reactions where both the participants are electrically charged. In such a reaction some kinetic energy must be available in order that the two nuclei can penetrate each other's coulomb potential barrier; consequently, at least for small energies, the reaction cross-section increases rapidly with the collision energy (Fig. 3b). Collision energy can be also expressed in terms of the temperature of the colliding particles and consequently, provided the temperature is high enough, these reactions can be observed in gases or liquids, hence their name—thermonuclear reactions.

When a thermonuclear reaction goes on in a hot nuclear gas in which the distribution of velocities is Maxwellian, the number of collisions with a collision energy, E, is (Fig. 4a):

$$dn = \sigma(E).f(E)dE$$

The rate of reaction as a function of energy is therefore

$$\nu = f(E)\,\sigma(E)$$

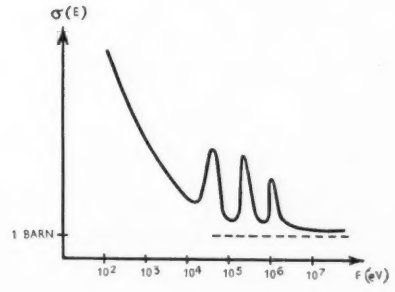
and it follows that the total reaction rate is

$$\nu_{tot} = \int_0^{\infty} f(E)\,\sigma(E)\,dE \text{ (reactions/cm}^3\text{-sec)}.$$

The rate of energy production is $W = Q.\nu_{tot}$ and for the TD reaction it is given by

$$W = 0{\cdot}95.10^{-23}\frac{n^2}{T^{2/3}}10^{-19.7/T^{1/3}} \text{ (watts/cm}^3\text{)} \ldots\ldots(1)$$

where n is the density of the nuclei and T is their temperature in 10^6°K. Such a reaction is consequently caused only by a minority of the nuclei in the nuclear gas; the majority represents a pool of heat energy (Fig. 4b).



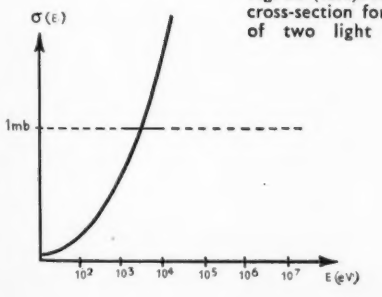


Fig. 3a (above). Reaction cross-section for neutron fission.
Fig. 3b (left). Reaction cross-section for fusion of two light nuclei.

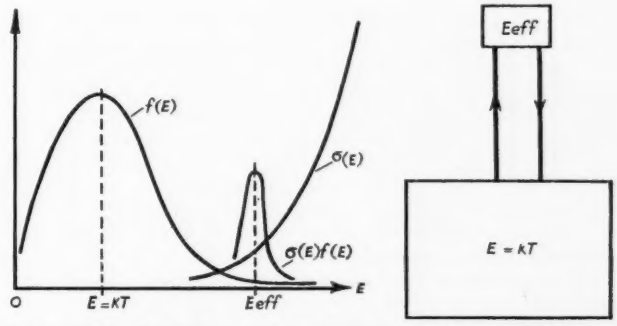


Fig. 4a (left). Reaction in a hot nuclear gas in which the distribution of velocities is Maxwellian. The majority of the nuclei represents a pool of heat energy, Fig. 4b (right).

Gases at Stellar Temperatures

As the temperature of a gas rises, the process of thermal ionization becomes more prominent. At temperatures which exist in stellar interiors the number of neutral atoms as compared with the number of electrons and positive ions is very small.

The degree of ionization in a system of particles in thermal equilibrium is given by Saha's equation, from which it follows that in the study of thermonuclear reactions one is concerned with a completely ionized gas. Such a medium is called a plasma and it can be regarded as a mixture of two gases, an electron gas and a positive ion gas, the latter consisting usually of atomic nuclei completely stripped of their electrons.

Plasma has many interesting properties. It tends to eliminate inside itself any disturbance in electric neutrality. Its conductivity at stellar temperatures is comparable with that of metals. In a magnetic field it behaves as a diamagnetic medium, with the result that it diffuses into regions where the magnetic field is weakest. When this diffusion takes place in a direction perpendicular to an applied magnetic field, H, the diffusion velocity is

$$V_d = 2.10^{-2}.Z\frac{\text{grad } n}{H^2\,T^{1/2}}\text{(cm/sec)} \qquad \ldots.(2)$$

where Z is the atomic number of the diffusing nuclei and n is their density.

This represents a substantial reduction on the diffusion velocity, v, in the absence of a magnetic field. In cases of interest, the ratio

$$v/v_d \sim 10^4\,A^{-1/2}\,Z^{-1}\,H^2\,T/\text{grad } n$$

and therefore it is obvious that if one wishes to insulate thermally a volume of plasma from the surrounding walls one should use a magnetic field to restrain the flow of particles to the walls.

Ignition of the Nuclear Flame

It has been mentioned that, in order to ignite a nuclear flame, it is necessary to heat a volume of plasma to a temperature of approximately 10^8°K. From Equation (1), showing the dependence of output power density on the temperature and density of nuclei capable of fusion, it is clear that the latter should be of the order of 10^{17} nuclei/cm³ if a flame with a useful output power density is to be produced. The heat content, w, per cm³ of such a hot plasma is then:

$$\begin{aligned} w &= 3\,nkT \\ &= 3.10^{17}.1{\cdot}37.10^{-16}.10^8 \\ &\sim 4.10^9\ \text{erg/cm}^3 = 400\ \text{joules/cm}^3. \end{aligned}$$

If the heating is to be accomplished within, say,

$$\tau = 10^{-4}\ \text{sec}$$

the power input per cm³ is

$$\frac{dw}{dt} = 4\ \text{MW/cm}^3,$$

which is not excessive by pulse-modulator design standards.

The most important problem in thermonuclear ignition is not the amount of heat energy required, but the manner in which this energy can be efficiently supplied to the plasma. Many ingenious mechanisms have been suggested for this energy transfer. After a close analysis most of them were rejected as impracticable or inefficient. The most promising methods seem to conform to the following pattern:

Preheating the plasma to some intermediate temperature.

Adiabatic compression of the preheated plasma to the desired fusion temperature.

Preheating can be achieved most simply by applying an electric field to the plasma. The energy of the electric field is transferred in the first place mainly to the electrons in the plasma, owing to their small inertia. The electrons then heat the nuclear gas in their collisions with the nuclei, so that the energy transfer from the electric field to the nuclei is effected through the medium of the electron gas.

Thus: $W_{\text{el.field}} \rightarrow W_{\text{electrons}} \rightarrow W_{\text{nuclei}}$

The heat, W, transferred from the electron gas at a temperature T_e to the nuclei at a temperature T_n per cm³ can be derived as follows.

The mean energy transfer in an electron-nucleus collision is

$$w_o = \frac{m}{M}\frac{3}{2}k\,(T_e - T_n) \qquad \text{(ergs)} \qquad \ldots.(3)$$

where m is the mass of the electron; and

M is the mass of the nucleus.

Therefore

$$W = w_o.n.\nu \qquad \text{(ergs/sec-cm}^3\text{)},$$

where $\nu = (3k\,T_e/2m)^{\frac{1}{2}}/\lambda_e$ = electron-nucleus collision frequency; and

$\lambda_e \sim k\,T_e^2/\pi e^4 n$ = mean free path of the electron.

For a deuterium plasma the heat transferred is given by:

$$W = 3{\cdot}5.10^{-18}\,n^2\,(T_e - T_n)/T_e^{3/2}\ \text{(ergs/sec-cm}^3\text{)} \qquad \ldots.(4)$$

The equation describing the heating of the nucleon gas is therefore:

$$\frac{d}{dt}\left(\frac{3}{2}nk\,T_n\right) = W \qquad \ldots.(5)$$

If T_e and n are constants

$$T_n = 1{\cdot}7.10^{-2}.n.T_e^{-1/2}\,(1 - T_n/T_e) \quad (^\circ\text{K/sec.}) \qquad \ldots.(6)$$

From this the time constant of the process is

$$\tau \sim 60\,T_e^{3/2}/n \quad \text{(sec.)} \qquad \ldots.(7)$$

Owing to energy losses from the heated plasma, the preheating process must be as fast as possible, certainly

$$\tau < 0{\cdot}1\ \text{msec.}$$

The particle density, n, in (7) is the density before the compression is effected. The density n′ after compression follows from the value of the maximum available magnetic field and it is

$$n' \sim 10^{17}\ \text{nuclei/cm}^3.$$

A practicable compression ratio is approximately 1,000. Therefore $n \sim 10^{14}$.

Using this value and the criterion for τ, the maximum temperature attainable by the preheating process becomes

$$T_e \sim 3\,T_n/2 \sim 0{\cdot}3.10^6\ (^\circ\text{K}).$$

This is, of course, only a rough estimate and improvement may be achieved by using a somewhat higher T_e or longer τ.

Compression. Let us assume that a body of plasma can be compressed axially or radially, or by a combination of axial and radial compressions. If the energy losses during the compression stroke can be neglected, the temperature rise is that corresponding to an adiabatic compression. This rise is then dependent only on the volume compression ratio. Thus

$$T/T_o = (V_o/V)^{\gamma-1} \qquad \ldots.(8)$$

where $\gamma = (m+2)/m$ and m is the number of degrees of freedom of a particle in the plasma.

In most cases one may take $m = 3$, so that $\gamma = 5/3$. However, if the time of compression is comparable or less than the mean time between two consecutive collisions, one must consider only those degrees of freedom in which the compression is directly effective.

Thus if the compression is uni-directional, $m = 1$, $\gamma = 3$. If it is bi-directional, $m = 2$, $\gamma = 2$.

The time between two DD collisions can be shown to be

$$t_{DD} \simeq 10.T^{3/2}/n \qquad \ldots.(9)$$

For $m = 3$, $\gamma = 5/3$, it follows that:

$$t_{DD} = \text{constant}$$

during the whole compression process.

Example: Typical values of n and T before compression are $n = 10^{14}$, $T = 2.10^{5}$°K. Then

$$t_{DD} \sim 10\ \mu\text{sec}.$$

The duration of the compression process cannot be much in excess of 100 μsec (owing to the energy losses impairing the adiabatic nature of the compression) and, therefore, the value of t_{DD} suggests that the factor γ is in the range

$$1 > \gamma - 1 > \frac{2}{3}.$$

Consider a compression of the above-mentioned cylinder of plasma. A feasible value for the axial compression ratio η_a is about 100 (e.g., original length 500 cm, final length 5 cm). This axial compression can be followed by a radial compression having a volume compression ratio

$$\eta_r \sim 20.$$

Thus the total volume compression ratio is

$$\eta = \eta_a . \eta_r \sim 2{,}000.$$

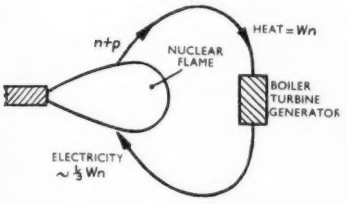
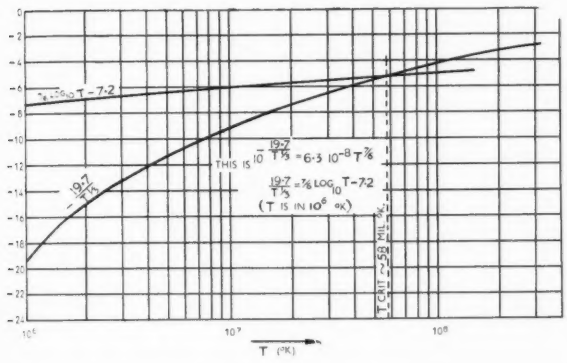


Fig. 5 (left). Diagram of heat-to-electricity conversion.

Fig. 6 (below). Calculation of the critical temperature for the TD reaction.



The corresponding temperature rise is given by

$$T/T_o = (2000)^{\gamma - 1}$$

and for m = 3, $T/T_o \sim 158$.

Thus, for example, if $T_o = 2.5.10^{5}$°K, the final temperature after the compression is given by

$$T \sim 40.10^{6}\text{°K}.$$

This temperature is close to the ignition temperature for a TD flame.

The only efficient method of plasma compression is one that uses growing magnetic fields. These may be generated either by currents within the plasma itself (pinch-effect compression) or by currents in coils outside the volume occupied by the plasma (travelling or standing pulse compression). The latter is more stable than the former, but less efficient.* The final solution may well incorporate both these types.

Which of the several types of igniter will be eventually used depends probably in the final scrutiny on parameters that at the present experimental stage are regarded as secondary, such as volume, weight and cost.

*The transversal instability of self-pinched plasma disappears in relativistic plasma; i.e., in a plasma in which the electron gas has an ordered relativistic velocity.[5]

†The mechanism of the particle loss may be different from that mentioned here, in a self-pinched plasma in which the loss may be much more severe.

Maintenance of the Nuclear Flame. Energy Balance

Whilst the nuclear flame might be difficult to ignite, it should not be so difficult to maintain. The intensity of the nuclear flame depends on the energy losses from the hot plasma in which the flame is ignited, which are mainly due to two mechanisms:

Particle loss from the plasma;
Bremsstrahlen.

The first of these losses is due to particles that penetrate the barrier of magnetic field outside the nuclear flame. In a plasma confined by external magnetic fields this loss occurs at the rate given by Equation (2) and can be made much smaller than the bremsstrahlen loss if sufficiently strong magnetic fields are used (this means in most cases $H \geq 10^{5}$ Oe).†

The bremsstrahlen loss is due to radiation emitted by electrons in their collisions with the nuclei and with each other. The electron-nucleus collisions contribute:

$$W_{B1} = 1.42.10^{-34}.n^2 \sqrt{T_e}\ (\text{watts/cm}^3) \quad \ldots.(10)$$

The electron-electron collisions contribute slightly less, so that the total bremsstrahlen loss is approximately:

$$W_B \sim 2.10^{-34}.n^2 \sqrt{T_e}\ (\text{watts/cm}^3) \quad \ldots.(10a)$$

Example: If $n = 10^{17}$ nuclei/cm^3, $T_e = 10^{8}$°K
$W_B \sim 20$ kW/cm^3.

If one considers the bremsstrahlen as the principal loss, it is possible to obtain the critical temperature below which a nuclear flame cannot maintain itself. This follows from the energy-balance equation:

$$1/3\ W_n = W_B \quad \ldots.(11)$$

which assumes that one converts the nuclear output into plasma heating by using the orthodox heat-into-electricity conversion, the efficiency of which is approximately 30% (Fig. 5). This equation is solved graphically in Fig. 6. The critical temperature for the TD reaction is about 58 million °K.

However, the path of the energy flux can be shortened considerably if one converts into plasma heat the kinetic energy of the charged products of the thermonuclear reaction. This implies the existence of the two following processes.

(1) The charged particles, p, must be confined within the nuclear flame for a certain time, t.

(2) These particles must be able to lose their energy to the plasma (to the nuclear fuel) in a time shorter than t.

The confinement of the charged particles results naturally from the plasma being in a strong magnetic field. Thus, for example, the charged product of the DT reaction is a He_4 nucleus with a kinetic energy of 3.5 MeV; its radius of curvature in a magnetic field H (Oe) is

$$r = 2.64.10^{5}/H\ (\text{cm}).$$

It is important that the linear dimension R of the nuclear combustion chamber is

$$R > r.$$

The appropriate magnitude of the magnetic field, H, is

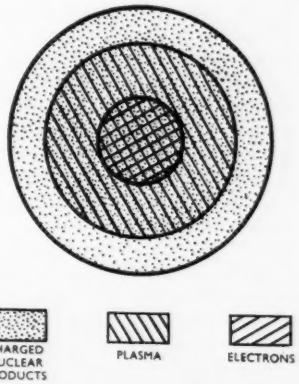


Fig. 7.

determined by the consideration of the particle loss from the plasma fuel. A typical value of the magnetic field is

$$H = 10^5 \text{ Oe.}$$

Thus:

$$r \sim 2.65 \text{ cm}$$

and one could have

$$R \sim 5 \text{ cm.}$$

The charged particles thus confined may be regarded as a thin gas of positive particles at a temperature of the order of 10^{10}°K. The mechanism of the confinement of this gas is made more efficient by the creation of a negatively charged centre in the nuclear flame (Fig. 7).

The transfer of heat energy from the hot cloud of nuclei, p, to the plasma fuel can be effected in two ways:

(a) through collisions between p and the plasma electrons;

(b) by means of the electric field, E, generated by the negative plasma centre. This field causes all the plasma particles to drift in a direction perpendicular to both E and the confining magnetic field, H, with a drift velocity (Fig. 8):

$$v_d = c\,E/H$$

The drift energy of the plasma nuclei is, therefore, M/m times larger than those of the plasma electrons. It thus follows that this process feeds energy preferentially into the nuclear component of the plasma fuel.

From this, it appears that the nuclear flame will be capable of self-maintenance without having to supplement it from the main neutron energy output. This supports even further the flame analogy we have been using so far.

The main problems connected with the design of the combustion chamber for such a self-maintaining nuclear flame is the necessity for a high magnetic field in a relatively large volume (probably of the order of several litres). Let us again assume a cylindrical geometry (Fig. 9). The loss W_{cu} in the cylindrical coil per cm length (for copper conductors at room temperature) is

$$W_{cu} = 1.65.10^{-6}.i^2.2\pi(r_o+\Delta/2)/\Delta \text{ (watts/cm).}$$

Expressing i in terms of H, one has:

$$W_{cu} \sim 10^{-5}\,(r_o/\Delta+\tfrac{1}{2}).H^2 \text{ (watts/cm).}$$

It is difficult to make $\Delta >> r_o$ as this results in a large magnetic energy being stored outside the combustion chamber. It seems that $2r_o = \Delta$ is a satisfactory compromise. Then

$$W_{cu} \sim 10^{-5}\,H^2 \text{ (watts/cm)} \qquad \ldots.(12)$$

This is clearly a very large power loss when one considers that $H \sim 10^5$ Oe. The length of the coil could be quite easily 20 cm, in which case the corresponding total power dissipation would be 2 MW. This obviously introduces a difficult cooling problem.‡

Another difficult problem, particularly when continuous operation is envisaged, is that of fresh fuel supply and of the disposal of the burnt nuclear fuel. Here, the development of an efficient plasma pump may prove to be the solution.

Energy Extraction from a Thermonuclear Reactor

The energy transfer from a thermonuclear flame represents a new challenge to an engineer, mainly because it contains features that are so different from those encountered in ordinary heat-transfer problems. When reactions are used in which most of the output energy is carried by a fast neutron flux, the walls of the combustion chamber need not partake in the energy transfer process as they can be made out of materials that are virtually transparent to the neutron flux. The energy of this flux can be trapped by a jacket of moderating material outside the combustion chamber. If the reaction used is the TD reaction, Li 6 can be used as moderator with the advantage of an added energy release from

$$\text{Li } 6 + n = T + \text{He } 4 + 4.8 \text{ MeV}$$

‡Some help may be derived from keeping the coil at liquid hydrogen temperature. Whether it would be practicable is difficult to say at present.

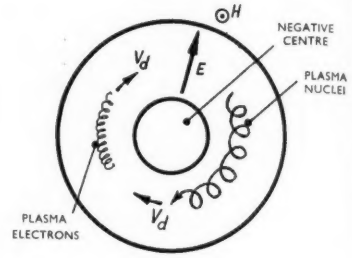


Fig. 8.

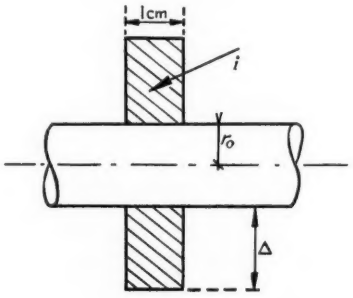


Fig. 9.

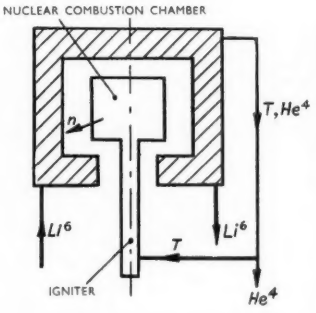


Fig. 10.

and the further advantage of breeding of the tritium fuel (Fig. 10).

The neutron flux emanating from a thermonuclear reactor could be used as a neutron source in connection with ordinary fission reactors. This would facilitate a control of a near-critical fast reactor assembly and if such a neutron source were sufficiently strong, fast natural-uranium and thorium reactors could be constructed (Fig. 11).

The other new feature in the removal of energy from a nuclear flame is that there is a hope of direct transformations of nuclear energy into electrical energy. This can be contemplated so far only in connection with reactions, such as the DD reaction, in which most of the nuclear energy appears in the form of kinetic energy of charged particles.

The mechanism of this transfer is best understood if one remembers that plasma is really an electrically-charged fluid and in a magnetic field it behaves as a diamagnetic medium. A plasma cylinder in a magnetic field may be, therefore, represented by a current layer, i, whose magnetic moment per cm length, μ_o, is the same as that of the plasma (Fig. 12). If the temperature of the plasma rises due to the ignition of a nuclear flame, the μ_o and therefore the i rises. The rising i induces currents, i′ in an output winding, S. When the plasma temperature ceases to rise (attains a maximum T_m), further extraction of energy from plasma is possible by decreasing the external magnetic field (this corresponds to the relaxation of pressure on the piston of a reciprocating engine). After having cooled the plasma to the initial temperature T_o, the cycle can be repeated. The efficiency of this cycle can be high

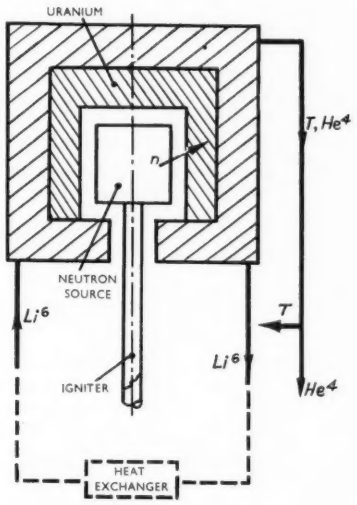


Fig. 11. Fusion-assisted fission reactor.

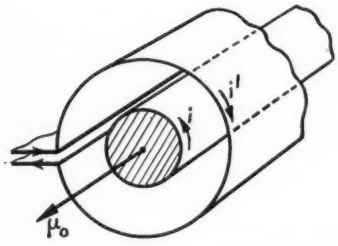


Fig. 12.

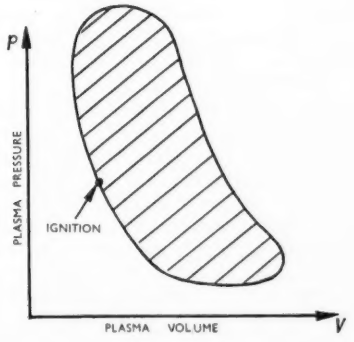


Fig. 13.

because Tm/To can be made very high (Fig. 13). However, it is likely that the overall efficiency of this type of energy transformation will be smaller than that of the orthodox chain of nuclear energy → heat energy → electrical energy. On the other hand, there is the obvious attraction of using an electrical transformer only instead of a heat exchanger, a boiler, a turbine, an electrical generator and a transformer.

A wide divergence of opinion exists on the time that will be required to turn some of these theories into reality, but a strong body of opinion exists which expects to see a zero energy fusion reactor in operation within ten years. Its development from that point is open to conjecture and it seems likely that a combined fission fusion system may be the most economic proposition, the fission reactor providing additional neutrons to maintain the nuclear flame.

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L'Energie Obtenue des Réactions Thermo-Nucléaires

Les concepts de base de l'énergie thermo-nucléaire y sont examinés, et une analogie est faite avec la flamme chimique ordinaire. Cela semble être une analogie permise, mais les températures d'ignition dans les deux cas diffèrent considérablement: 1.000° *K et* 10⁸ °*K.*

Un nombre de réactions sont possibles où la fusion des éléments dégage de l'énergie, mais la réaction D.D. est probablement celle qui est la plus appropriée aux systèmes réacteurs initiaux. Les problèmes de la construction d'un réacteur sont divisés entre ceux qui ont trait à l'ignition, l'entretien de la flamme et l'extraction de l'énergie. On en tire la conclusion qu'alors que l'ignition s'avère difficile avec le préchauffage suivi d'une compression magnétique, un système de travail peut être créé. L'entretien de la flamme pose moins de problèmes pourvu que la flamme puisse être contenue dans l'espace libre. Un aimant avec une dissipation d'énergie de 2 MW devrait s'acquitter de cette tâche pour un bac de réacteur de quelques litres seulement. L'extraction d'énergie par le bombardement direct du réfrigérant par des neutrons introduit une nouvelle idée du transfert de chaleur. Il est concevable que de l'énergie électrique puisse être directement extraite de la flamme circulaire en faisant le plasme former le circuit primaire d'un transformateur.

Krafterzeugung aus thermischeri Atomkraft Reaktionen

Grundlegende Begriffe der thermischen Atomkraft werden einer Prüfung unterzogen; es wird auf die Analogie der chemischen Flamme hingewiesen. Dies würde als Analogie erlaubt erscheinen, jedoch sind die Zündungs Temperaturen in beiden Fällen weitaus verschieden: 1.000° *K und* 10⁸ °*K.*

Es gibt eine Anzahl von Reaktionen, die durch Fusion von Teilen die Möglichkeit der Freimachung von Energie geben, jedoch dürfte die D.D. Reaktion die geeignetste sein, um mit Reaktor Systemen zu beginnen. Die Probleme, die bei dem Bau von Reaktoren auftreten, können unterteilt werden in diejenigen, die die Zündung betreffen, diejenigen, die die Erhaltung der Flamme betreffen, und die Ausbeutung der Energie betreffen. Es wird der Schluss gezogen, dass ein praktisches System entwickelt werden kann, wenn auch Zündung schwierig ist mittels Vorwärmung, auf die magnetische Kompression folgt. Die Aufrechterhaltung der Flamme bringt weniger Probleme vorausgesetzt, dass man die Flamme im freien Raum begrenzen kann. Ein Magnet mit einer Energie Abgabe von 2 MW sollte dies für einen Reaktor Behälter von ein paar Litern erzielen. Energie Ausbeutung durch direktes Bombardieren des Kühlmittels mit Elektrons bringt einen neuen Begriff von Wärme Uebertragung. Man könnte daran denken, elektrische Energie direkt der kreisförmigen Flamme zu entziehen, indem man das Plasma als Primärkreis eines Transformators ausbildet.

Energía obtenida de la Reacciones Thermonucleares

Se examinan los conceptos básicos de la energía termonuclear, haciéndose una analogía con la llama química ordinaria. Esta analogía parece ser permisible, pero la temperatura de encendido en los dos casos es del todo diferente: 1.000° *K y* 10⁸ °*K*

Son posibles un número de reacciones donde la fusión de los elementos libera energía, pero la reacción D.D. es probablemente la más adecuada para sistemas de reactor iniciales. Los problemas de la construcción de un reactor se dividen en aquellos que se relación con encendido, mantenimiento de la llama y extracción de energía. La conclusión a que se llega es que mientras que el encendido es difícil, por medio de precalentamiento seguido por compresión magnética, se puede evolucionar un sistema que trabaja. El mantenimiento de la llama presenta menos problemas siempre que la llama pueda ser contenida en espacio libre. Un imán con una disipación de energía de 2 MW debe conseguir esto para un recipiente de reactor de unos cuantos litros. La extracción de energía por el bombardeo directo del refrigerante con neutrones presenta un nuevo concepto de transferencia de calor. Es concebible que la energía eléctrica podria ser extraída directamente de la llama circular haciendo que la plasma forme el circuito primario de un transformador.

MERLIN—Medium Flux Research Reactor

by

D. R. CHICK, M.Sc., F.Inst.P., M.I.E.E., and
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PART 2

The safety aspects of the design are discussed with a description of the control and instrumentation system and of safety precautions for core adjustment and maintenance. The article also deals with fission-product activity and effluent disposal, concluding with a brief outline of the operating programme.

IT is essential that any reactor be designed and operated so that the possibility of it getting out of control is negligible, and the fission products produced in the core will remain contained until they can be removed in a controlled fashion during the reprocessing of the fuel. In about four years' time these fission products in Merlin will have about one megacurie of radioactivity associated with them, and it is obviously necessary that the possibility of this activity escaping to the surrounding countryside be minimized.

Also, Merlin will be the first reactor owned and operated by a private body in the British Commonwealth, and it is a prototype of research reactors that will be exported and built in other parts of the United Kingdom; further reasons, although obviously not the prime ones, why the reactor must be operated safely and satisfactorily.

Basic Philosophy of Control

Considerable effort has been spent on the safety aspect of the design, the major part of the effort of the team at Aldermaston, for eight months, being spent working on discussions with the U.K.A.E.A. Reactor Locational Panel concerning the safety of the reactor. After various design changes, it was decided that the reactor could be sited at Aldermaston without containment. In all these discussions it was assumed that the reactor control system was worthless, the entire emphasis being placed on designing and operating the reactor so that it was inherently capable of suppressing any conceivable power surge.

To ensure that the built-in safety of the reactor is not unnecessarily called upon, the control system is very stringently designed, and the maximum rate of reactivity addition by the control units is restricted to the conservative values given in Table I.

TABLE I—NORMAL MEAN RATES OF REACTIVITY ADDITION

Unit	Reactivity	Mean Rate $\pm$ d ρ/dt
Fine	0.005	20×10^{-5} sec^{-1}
Coarse	0.055	4
Two safety ...	0.11 (total)	7

The system is designed to "fail safe": thus whatever fault occurs in the system it tends to produce a safe condition of the reactor, i.e., it sounds an alarm or starts to make the reactor sub-critical. The neutron density is monitored at all times, or if it is not, the reactor is fully shut-down, with the coarse unit and both safety units in the core. In order to ensure that the antimony-beryllium source, which provides the initial neutron flux when the reactor is sub-critical, cannot be simply removed in one operation, it has been split into a number of small sources; one is attached to each fuel element. The reactor control system is designed so that there are no modifications necessary to it during operation, maintenance or testing. This will mean that on some occasions the necessary procedure may be rather longer than the minimum possible, but it will ensure that the control system is always available to protect the reactor.

Control and Instrumentation System

The coarse control unit will cover all expected reactivity variations when working at 1 MW or less. If the reactor is operated in the range 1 to 5 MW, it will cover equilibrium but not peak poisoning. Withdrawal of the coarse control unit will take 25 min., giving a mean rate of addition of reactivity of $4 \cdot 10^{-5}$/sec., and a peak rate of about twice this value. If the unit is driven out continuously as the reactor passes through critical, the rate of rise of power will be such that there is ample time for the automatic protection devices, or the operator, to release the safety rods before damage is done to the reactor. At the peak rate of reactivity addition it would take two minutes to pass from critical to prompt critical.

The fine unit, controlling 5×10^{-3} in reactivity, has a continuously variable speed control permitting full travel in a minimum of 25 sec., i.e., at full speed the mean rate of reactivity change will be 20×10^{-5}/sec. When used with automatic control, this will enable the servo-system to hold the power steady for all normal reactivity variations. The most rapid normal variation will be due to moving the coarse control unit to adjust the working point of the fine unit. Since the reactivity controlled by the fine unit is only 5×10^{-3}, no fault in the fine unit control system can make the reactor prompt-critical.

The two safety units will be withdrawn together in 25 minutes, giving a mean rate of rise of reactivity of $7 \cdot 10^{-5}$/sec. The coarse control unit and the safety units will be held by magnets which can be released in an emergency; these units will then fall into the reactor core in about 0.3 sec.

A total of six boron-coated ion chambers and one fission chamber will be used for neutron flux measurement. Two ion chambers, one at each operating level, will be connected in parallel and will feed a linear current-measuring circuit which will provide an accurate indication of reactor power and will also provide the control signal for the reactor power stabilizing servo-system. A further pair of similar chambers, one at each operating level, will feed a logarithmic d.c. amplifier whose output will be differentiated to provide a reactor power period indication. Too short a period will trip the safety circuits, the initial setting being 15 sec.

These four ion chambers will be behind the 4-in. lead thermal shield and will also have a further 2 in. of individual lead shielding. This shielding, more than is normally provided, is to enable the rather wide power range

of the reactor to be covered with only two sets of detectors. Two further ion chambers, moving with the core, will feed shut-down amplifiers, whose function will be to trip the safety circuits in the event of the reactor power becoming too great. Fig. 1 shows a simplified diagram of the control system.

A fission chamber will be used to indicate the reactor power when it is too low for detection by the ion chambers. The antimony-beryllium neutron sources will ensure that the fission chamber gives a detectable counting rate even when the reactor is shut-down and the safety rods are inserted. As the reactor is brought towards critical, the sub-critical multiplication factor will rise and increase this counting rate, so that the operator will know when

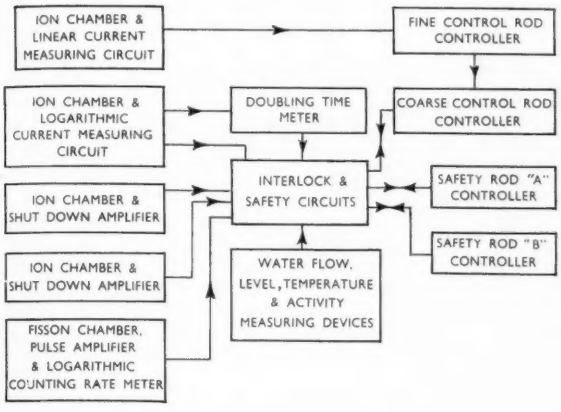
ION CHAMBER & LINEAR CURRENT MEASURING CIRCUIT
FINE CONTROL ROD CONTROLLER
ION CHAMBER & LOGARITHMIC CURRENT MEASURING CIRCUIT
DOUBLING TIME METER
COARSE CONTROL ROD CONTROLLER
INTERLOCK & SAFETY CIRCUITS
SAFETY ROD "A" CONTROLLER
ION CHAMBER & SHUT DOWN AMPLIFIER
SAFETY ROD "B" CONTROLLER
ION CHAMBER & SHUT DOWN AMPLIFIER
WATER FLOW, LEVEL, TEMPERATURE & ACTIVITY MEASURING DEVICES
FISSON CHAMBER, PULSE AMPLIFIER & LOGARITHMIC COUNTING RATE METER

Fig. 1. Simplified block diagram of control system.

the reactor is near the critical condition. There will be an overlap of about one decade between the ranges of the fission chamber and the ion chambers.

When the power is raised beyond the range of the fission chamber, it will be automatically withdrawn to a region of lower flux. If the fission chamber counting rate indication is too high or too low, or if this chamber is not fully inserted, the safety circuits will be tripped unless the main reactor control selector switches are set to "operate" and the logarithmic ion chamber circuit is reading above a pre-set minimum power.

Instruments are also provided for checking cooling water flow and the temperature and the level of the water in the reactor. Unsatisfactory indications from these instruments will either sound an alarm or shut-down the reactor, according to the severity of the condition. For example, at powers greater than 1 MW full water flow is required, and if only one of the two primary pumps or one of the two secondary pumps is operating an alarm will sound. Failure of both primary or both secondary pumps will shut-down the reactor. At lower powers, only one primary or one secondary pump is required and failure of either will sound an alarm. When the main selector switches are not set to "operate" no water flow is required.

Four γ-radiation and two slow neutron monitors will check the level of radiation in the experimental area around the reactor. A comprehensive system of further monitors will check for activity in the reactor area. All these monitors will connect into alarm circuits, and danger signals from some of them will also initiate further action. For example, the detection of activity in the secondary cooling water will result in the secondary pumps being

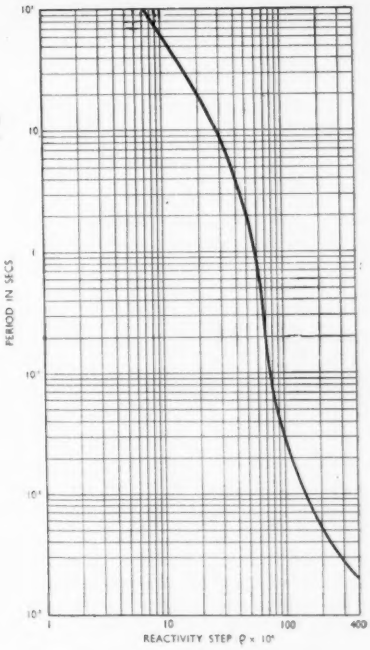

Fig. 2. Period as a function of step reactivity input.

stopped and automatic valves in the pipes to the lake being closed.

To make changes in the arrangement of the fuel or reflector elements of the core, it will be raised to a level 4 ft. above the upper experimental position. Loading poles will be provided for handling the fuel and reflector elements, and will be non-interchangeable, so that full fuel elements cannot be mistaken for reflector elements. A complete fuel box of fourteen plates will control 10^{-2} in reactivity. To allow fine trimming of the reactivity invested in the core, fuel element boxes with one, two, four and six plates will also be provided which are designed for handling with the reflector element tool. The worst mistake possible would then be to add a six-plate box instead of a one-plate one, thus adding about 4×10^{-3} more reactivity than was intended. If either of the handling poles are removed from their racks, without specified conditions of the reactor state being satisfied, an alarm will sound.

The safety circuits will be arranged so that a single danger indication will give a shut-down. Each detector which can initiate a shut-down action will work through two separate control sequences, each of which can release both the safety units and the coarse control unit. Failure of either control sequence will not affect operation of the other, so that there is protection against "fail danger" faults such as welded relay contacts. Also, the circuits are designed throughout on "fail-safe" principles.

TABLE II—CONDITIONS WHICH CAN CAUSE SHUT-DOWN OF MERLIN

Some of these conditions, e.g., those concerning the fission chamber, do not give shut-down in all circumstances

Excess power indicated by either shut-down amplifier.
Excess power indicated by logarithmic ion current amplifier.
Reactor period (doubling time) too short.
Fission chamber counting rate too high or too low.
Fission chamber not at inner limit position.
Cooling water temperature too high.
Cooling water flow inadequate, power greater that 1 MW.
Fission product activity in cooling water.
Pool water level too low.
Any one of five emergency shut-down buttons pressed.

A list of conditions causing shut-down of the reactor is shown in Table II. Table III gives a list of less serious conditions which operate the warning system.

TABLE III—CONDITIONS WHICH CAUSE ALARMS

Some of these conditions, e.g., core loading pole not in cabinet, do not give an alarm in all circumstances

Shut-down circuits tripped.
Cooling water temperature too high.
Cooling water flow inadequate.
Ventilation above pool inadequate.
Pool water level too low or too high.
Fission chamber not fully withdrawn when operating at power.
Excess radiation indicated by any one of a number of fixed monitors.
Core loading poles not in their cabinet.

In addition to the safety circuits, there are interlock circuits, indicated in Fig. 1, which govern the conditions under which various maintenance operations can be carried out. Selector switches provide for operation, stand-by, working on the core, moving the core and testing the coarse rod mechanism under conditions which ensure maximum safety. These circuits ensure, so far as possible, that if the operator tries to do something potentially dangerous, the controls he uses will be inoperative. There are thus four lines of defence against serious accidents: (1) operator training and personnel discipline; (2) interlocks; (3) automatic shut-down devices; and (4) the basic design of the reactor itself.

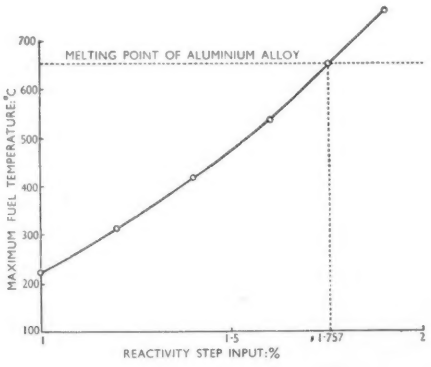

Fig. 3 (above). Estimated maximum fuel temperature as a result of excursion with various excess reactivities. Mean water temperature, 40°C.

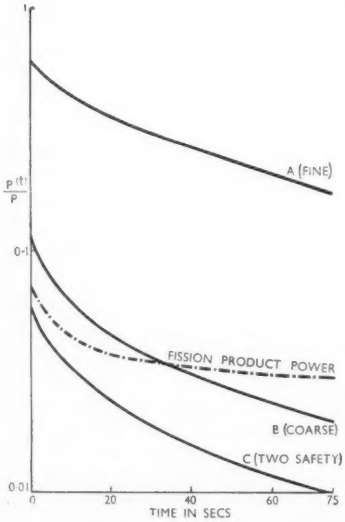

Fig. 4 (left). Relative reactor power due to a negative step reactivity input. (A), $\rho = -0.005$; (B), $\rho = -0.055$; (C), $\rho = -0.11$.

Reactor Kinetics

The neutron lifetime in Merlin when fully reflected by water is about 60 μsec. Slowing down accounts for 10% of this time, the remaining 90% being spent in thermal diffusion.

After a step reactivity input there will normally be a short rapid rise in power followed by an exponential increase with time. Under these conditions, the stable period, i.e., the time taken for the power to increase by a factor of e(=2.716), is shown in Fig. 2. During normal operation a reactor power period of about 30 sec. will be used when going to full power; the time taken from critical to 5 MW will then be about 11 min.

The transient behaviour of the reactor fuel-plate temperature has been estimated from the data provided by the Borax I reactor tests.[1] The method of analysis due to Lucknow and Widdoes[2] was used. The reactors are compared in Table IV. As regards the moderator, coolant, reflector and fuel-element sheath, the two reactors are the same. The results of this analysis are given in Fig. 3. Based on these results, a maximum step reactivity change of 10^{-2} is imposed on all operations to be performed in Merlin. Such a step would produce a power surge leading to a fuel-plate temperature of about 220°C; the melting point of the fuel elements is about 660°C. The reactor period during this power surge is estimated to be approximately 20 msec.

TABLE IV—THE CORES OF BORAX I AND MERLIN

	Merlin	Borax I
Fuel, % U235	>90	90
U235 content per box, gm. ...	140	138.6
Plate spacing, in.	0.187	0.177
Water channel, in.	0.130	0.117
Effective neutron lifetime, μsec. ...	~60	65 ± 5

The behaviour of the reactor power, as a function of time, after the control rods have been instantaneously inserted is shown in Fig. 4. It will be noticed that with a full emergency shut-down, when both safety rods drop into the core, the reactor power is mainly due to the fission products, assuming the reactor has been operating at power for some time. In such a case the total power will be about 5% of the initial value after 1 min. If the core contained no fission products, the power level would have been 1% of the initial level after 1 min.

Poisoning

The effect of xenon poisoning on reactivity as a function of operating time is shown in Fig. 5; start-up from an unpoisoned state is assumed to occur at zero time and the power is kept constant at 5 MW for 25 hours, after which shut-down occurs. The equilibrium reactivity loss is about 3.2×10^{-2}. The peak reactivity loss, occurring ten hours after shut-down, is about 7.5×10^{-2}. If the reactor was not brought back to the operating power immediately, shut-down would have to continue for another 32 hours.

The chosen schedule of operation at Aldermaston has a maximum time of ten hours per week at 5 MW—to limit fuel burn-up and fission products. In this case there will be reactivity available to over-ride the increase in xenon

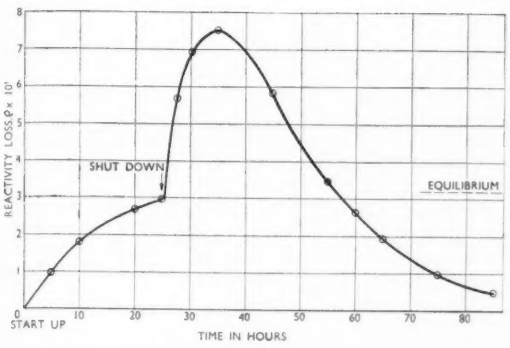

Fig. 5. Effect of xenon poisoning on reactivity as a function of operating time, 5 MW.

poisoning for a period of about half an hour after shut-down.

The samarium poisoning of the core will reach an equilibrium concentration corresponding to a reactivity loss of 1.2×10^{-2}. If the reactor is continuously operated at 1 MW this concentration will nearly be achieved in a time of the order of 100 days. Even if the reactor is operated at 5 MW for ten hours per week during this period, the time taken to reach effective equilibrium will not be very much shorter; about 80 days. As this is a relatively long time effect, and reaches an equilibrium value, fuel will be added to the core to compensate for this reactivity loss as it occurs, rather than as part of the initial investment.

The maximum extra reactivity loss upon shut-down due to samarium will be about 10^{-3} after continuous operation at 1 MW, the time constant associated with this loss being about 3 days. The corresponding extra loss at 5 MW will be 3×10^{-3}; after operation for ten hours per week at this power and thirty hours at 1 MW, a reactivity loss of 10^{-3} will be observed, if the maintenance period is two days.

Fission Product Activity

In order to assess the activity that could be released in an accident, the gross fission product activity has been estimated. A provisional programme of operation has been made and on this basis the burn-up of fuel has been calculated; the results are shown at the top of Fig. 6. The data for the estimates were taken from Howlett[3] *et al.*, who give values enabling the total activity to be obtained for irradiation and decay times, the sum of which lies between 1 and 1,000 days, the decay time being at least one day.

Treating each period of operation separately, the amount of activity at the end of the period has been calculated allowing decay times of one to several hundred days in each case. Day-to-day variations in reactor power have been neglected, since these, whilst affecting the instantaneous amount of activity in the core, produce only a negligible variation from the amount calculated, assuming continuous operation at the mean power, and a decay of one day or longer.

Results are shown in Fig. 6. The manner in which the activity builds up during operation is shown for the second period, but the form of the subsequent changes in activity is not given in detail. During the first six months the activity is small (less than 2 curies); it then rises and, after four years, when the reactor will be operating just below the proposed mean power, the activity amounts to about 0.7 megacurie.

The total activity in the core depends largely upon the power averaged over an immediately preceding period of the order of 100 days. However, when considering hazards associated with particularly dangerous isotopes, it is necessary to consider these specific cases in more detail, since a gradual build-up of long-lived activities will occur throughout the life of the fuel. For example, the activities of 54-day Sr89 and of the 28-year Sr90—64-hour Y90 chain have been calculated; the results are also shown in Fig. 6. At the end of four years the activities are 27 kilocuries and 4.5 kilocuries respectively. In all these calculations it has been assumed that the same reactor core would be used throughout the four-year programme; this would tend to over-estimate the amount of activity in the core after about the first eighteen months.

Effluent Disposal

The effluent from Merlin, as from most other reactors, will be of all three types: gaseous, liquid and solid. The methods envisaged for dealing with it are conventional, except that the scale of the effort will be new for the United Kingdom; lying between those radio-chemical units which do not require an engineered effluent plant and the large effluent plants built on some of the U.K.A.E.A. sites.

The gaseous effluents will be hydrogen, nitrogen and argon, the latter two being active but with relatively short half-lives of 6.7 sec. and 1.58 hr. respectively. The input air to the reactor building will be filtered, the efficiency of filtration being about 90% for particles of 1 μ diameter; this will reduce the need for changing the output filters which will contain some radioactivity. These output filters will have an efficiency of about 99% for particles of 1μ diameter and will reduce the solid matter, hence the activity, from the output chimney stack. All air from the reactor building will be filtered in this way before passing

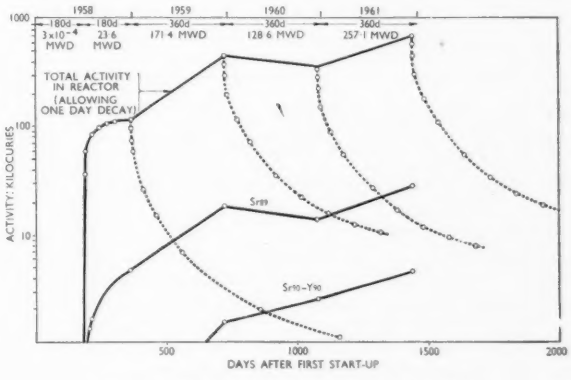

Fig. 6. Fission-product activity in MERLIN.

out through the stack. This output, after the filter, will be monitored. Under normal operating conditions this effluent will be safe at the stack output. Fixed radiation monitors in the region of the main laboratory and on the laboratory boundary will also help to ensure that no undue activity is being released.

Solid active effluent will consist of two main types: materials which have been in contact with active materials and irradiated materials. Materials with a surface layer of activity will be decontaminated and the resultant liquid will be treated as normal active liquid effluent. If the activity is in the bulk of the material, such as would occur after neutron irradiation, then the material will have

to be stored either permanently or until arrangements are made to transport it for permanent disposal elsewhere. Provision is made in the storage building for the containment of about 250 curies of experimental material. The extension of this storage system will depend on the amount and type of experimental work undertaken with the reactor in the future.

Liquid effluents from the reactor area will be considered as of two types, depending on their region of origin, "probably active" and "possibly active". All liquid matter in the reactor area will be channelled to an effluent plant by two main pipe-lines corresponding to the above designations. Delay tanks will be provided at the input and output of the effluent plant. The output delay tank will feed into the main secondary cooling water output to the lake to assist initial dilution. The mean level of activity at the output of the effluent plant may be about 2×10^{-1} $\mu c/cm^3$. The activity released from the plant will be continuously monitored and recorded, as will the water flow from the effluent plant.

Reactor Site

The reactor and ancillary buildings stand on the side of a hill which slopes down sharply to Aldermaston lake, the outlet of which flows into the River Kennet, thence into the Thames. The secondary cooling water circuit is taken from the lake and returned to it. Some effluent is also discharged into the lake after stringent monitoring precautions have been taken.

Separate buildings of concrete and brick construction are located on successively lower levels (Fig. 7). They contain:
(a) The reactor, control room, laboratories, ventilation plant room, visitors' and conference room, lavatories.
(b) Boiler-house with oil fuel store, fission product detector, primary pumps, heat exchangers and water plant.
(c) Active equipment store.
(d) Active effluent plant, secondary water circuit pump house.
(e) Changing room, showers and Elsan closet, etc., situated to the side of the active equipment store.
(f) Two huts, one for experimental and one for design work, located on approximately the same level as the reactor.

The area occupied by the reactor and ancillary buildings, including open spaces between, is approximately 31,000 sq. ft. Of this, 13,500 sq. ft. is the superficial area of the buildings. A site of this size is considered to be the minimum possible for a reactor of the Merlin type. The size of the site is expected to grow, especially in experimental laboratories, as the experimental work about the reactor expands. Space exists round the reactor building and to the south of it for extension of buildings.

The above buildings, except the reactor, the huts and the boiler-house with its oil fuel store will be fenced off as the "Active Area"—"active" in the sense that contamination might be possible.

Movement of stores, fuel and equipment between the reactor building and the active area will be by a fork-lift truck fitted with a crane jib. A ten-ton crane and runway is provided above the reactor.

The primary water circuit and the active effluent from sinks, etc., in the laboratories are ducted under the reactor building to the active area. Surface drainage and storm-water drains from the hill on which the buildings stand go to Aldermaston lake; this output to the lake is monitored for activity.

Fixed radiation monitors, listed below, are located as shown in Fig. 7.

γ-radiation	17
Thermal neutron	2
Fission product	1
Hand and foot	1

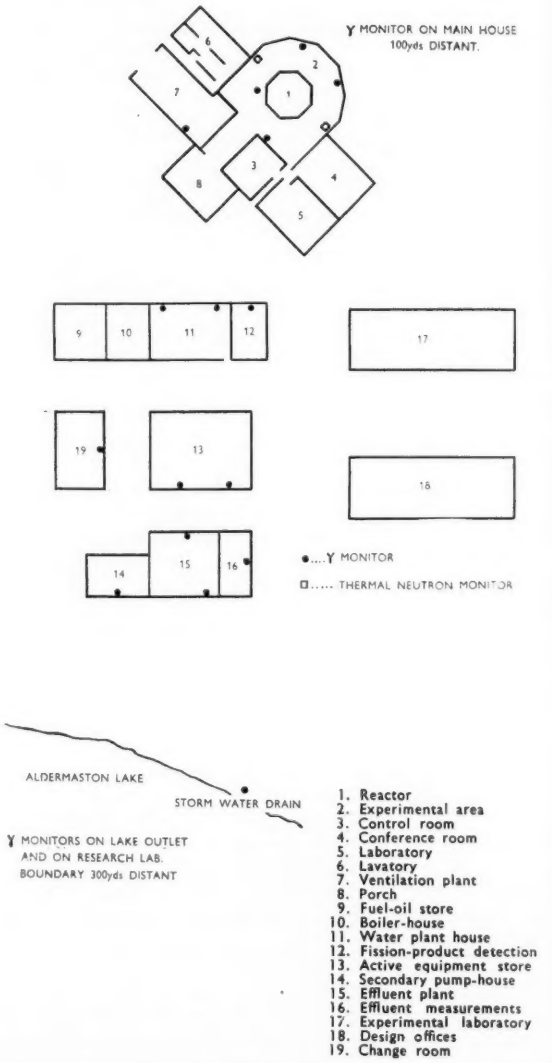

Fig. 7. Site plan of MERLIN and ancillary buildings at Aldermaston.

Of the γ-ray monitors, one is located above the reactor, one on the outlet of Aldermaston lake and one each on the main house and the north-west boundary of the research laboratory area.

Power Consumption

The power consumption allowed for from the mains is 500 kW at full reactor power. Emergency power in the event of mains failure is supplied by Diesel generators which can be started up within 3 min. The estimated power required to operate the entire control system, monitors and warning lights, the ventilating fan above the pool and lighting for all the reactor buildings is 15 kW. In the interim, between the failure of the mains and the starting up of the emergency Diesel generators, a battery supply is automatically switched on and supplies power to control panel indicators and emergency lighting in the control room, experimental area and fission product detection room, also the ventilation fan above the pool.

Programme

The reactor building will be weatherproof by the late summer of this year. The reactor components and instrumentation will then be installed and it is expected that the reactor will become critical early in 1958. No inflexible date has been set for the initial critical experiment, as the prime requirement is that adequate time is available for testing the entire system before fuel is placed in the reactor. However, every effort will be made to ensure that there is no undue delay. At the moment of writing (November, 1956), the reactor foundation and the reactor building foundations are in position, the water plant house and the active equipment store are almost complete. The first experimental laboratory and the design offices are complete and in full use.

The operating programme, once the reactor has been critical, is given in Table V. The first year will be spent testing and investigating the reactor as a prototype. In this case there is no incentive to reach the full operating power of 5 MW quickly, as it will be convenient, during a large part of the investigations, to have a minimum of radioactivity in the fuel elements, as this will ease handling problems.

TABLE V—ESTIMATED OPERATING PROGRAMME OF MERLIN

Period	Weekly Schedule	Equivalent to	Irradiation MWD
1 Jan.-June, 1951 180 days	30 hr at 10 W	180 days at 1.8 W mean	3.2×10^{-4}
2 July-Dec., 1958 180 days	20 hr at 100 kW 20 hr at 1 MW	180 days at 131 kW mean	23.6
3 1959 360 days	30 hr at 1 MW 10 hr at 5 MW	360 days at 476 kW mean	171.4
4 1960 360 days	35 hr at 1 MW 5 hr at 5 MW	360 days at 357 kW mean	128.6
5 1961 360 days	120 hr at 1 MW	360 days at 714 kW mean	257.1

Total irradiation=580.7 MWD.

Acknowledgments

The design work reported above has been carried out jointly by the A.E.I.-John Thompson Nuclear Energy Company and the A.E.I. Research Laboratory at Aldermaston.

The authors are indebted to Dr. T. E. Allibone for permission to publish this paper and for his encouragement in the work reported.

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MERLIN—2ème Partie

Dans ce second article sur le réacteur type piscine avec un rendement de chaleur maximum de 5 MW, on étudie les divers aspects du contrôle et de l'instrumentation. Dans les tiges de sécurité et contrôle sont incorporés 0.005 de réactivité (fine), 0.055 (grossière) et dans les deux tiges de sécurité un total de 0.11. Tous les aspects du système de contrôle et de la conception générale se portent vers la condition panne-sans danger selon laquelle tout accident a pour résultat la fermeture du réacteur.

Les mesures du flux sont effectuées par six chambres à ions revêtues de bore et une chambre de fission pour assurer le contrôle aux deux niveaux de marche du réacteur. En outre, un contrôle étendu de la santé dans la région avoisinante sera institué. Un système complexe de verrouillage fait en sorte que le chargement des éléments de combustible ne peut pas être entrepris sans que toutes les tiges de sécurité soient en place.

MERLIN—Teil 2

In diesem zweiten Aufsatz über den Schwimmbad Reaktor mit einer grössten Wärmeerzeugung von 5 MW werden die verschiedenen Aufgaben der Regelung and der Einrichtung der Messinstrumente diskutiert. In den Regelungs- und Sicherheits-Stäben sind 0,005 für Fein-Regulierung der Reaktivität, 0,055 für Grob-Regulierung eingesetzt und in den beiden Sicherheits-Stäben insgesamt 0,11. Das ganze Regulierungs System und die Konstruktion im allgemeinen sind in dem Sinne durchgearbeitet, dass ein absoluter Sicherheits-Zustand geshaffen wird, bei dem ein Unfall jederzeit dazu führt, dass der Reaktor abgestellt wird.

Die Messungen des Flusses werden in sechs mit einem Bor Ueberzug versehenen Ionen Kammerns durchgeführt, während eine Spaltungs Kammer für Ueberwachungs-Signale benutzt wird, die in beiden Arbeitsstufen des Reaktors ansprechen. Ferner wird eine ausgedehnte Gesundheits-Ueberwachungs Apparatur in der gesamten Umgebung installiert werden. Das System völliger Abhängigkeit der Schaltungen untereinander dient als Sicherung, sodass die Brennstoff Patronen nicht eingesetzt werden können, wenn nicht alle Sicherheits-Stäbe in Arbeitsstellung sind.

MERLIN—Parte 2

En este segundo artículo sobre el reactor tipo piscina de natación con un rendimiento máximo de calor de 5 MW, se discuten los diversos aspectos de control y de instrumentación. Invertidos en las varillas de control y de seguridad hay 0,055 reactividad (fina), 0,055 (basta) y en las dos varillas de seguridad un total de 0,11. Todos los aspectos del sistema de control y el diseño general tienden hacia la condición "falla-seguridad" mediante la cual resulta que en caso de cualquier accidente, el reactor es aislado.

Las mediciones de flujo se hacen por medio de seis cámaras iónicas revestidas de boro y una cámara de fisión para proveer supervisión a ambos niveles de funcionamiento del reactor. Además, en la zona circunvecina se instalará una supervisión extensa de salud. Un complejo sistema de trabas asegura que no se pueda llevar a cabo el cargado de elementos de combustible sin que todas las varillas de seguridad estén en posición.

Radio-isotope in

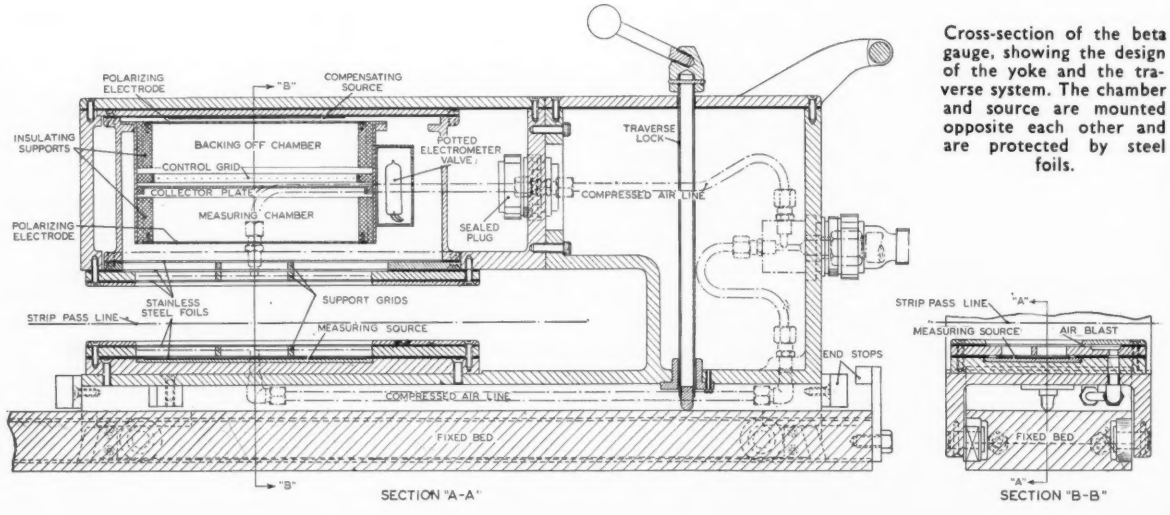
Two gauges designed for arduous conditions such as those obtaining in steel mills are described. The first is a beta gauge designed for cold-rolled steel and the second a gamma or Bremsstrahlung gauge for hot-rolled strip.

General view of the radiation gauge for use on hot-rolled strip at the works of Arthur Lee and Sons Ltd., Sheffield.

RADIATION gauges have been in operation on steel rolling mills for some years, but until recently the source of radiation used was the X-ray tube. The X-ray tube is an adaptable source of radiation which can be turned on and off at will and can be adjusted in terms of voltage and current to suit a particular thickness being rolled. It is, however, essentially a relatively delicate piece of equipment, and the necessity of bringing in high-voltage cables into the vicinity of the mill is a serious disadvantage. The greatest problem, however, associated with continuous use is the fluctuations in the strength of the radiation due to changes in supplies and changes in the characteristics of the tube. As a result, it has always been necessary to use a split-beam type of tube and a comparator system measuring radiation transmitted through the strip against the radiation from the other beam having passed through a wedge or other suitable absorber. The unpredictable changes in radiation strength and the complicated system of servo-control that is necessary to overcome this, taken in conjunction with the problem of high-voltage supply and the relative short life of the tubes, have led to an increasing use of radio-isotopes as the source of radiation.

The most serious disadvantage of a radio-isotope source in comparison with an X-ray tube is the inability to switch off the radiation. In general, however, distances between the location of the source and operators are large and surrounding machinery is so heavy that complete safety can be assured. Furthermore, with foil and capsule sources now available, even serious cobbles cannot cause a general distribution of activity. The sources which have a rate of emission independent of outside influences can be mounted in a small space in the body of the mill and provided with remotely and automatically operated shields.

The techniques associated with radio-isotope measurements and steelwork installations at present involve rather different backgrounds, and in order to combine experience in heavy engineering application with radiation experience Davy and United Engineering Co. Ltd., of Sheffield, have been working in collaboration with Isotope Developments Ltd., of Aldermaston, to develop radiation gauges suitable for operation on metal lines. As a result of this partnership, three types of gauge have been developed; a beta gauge, which has now been in operation on tin-plate lines for more than twelve months; a gamma gauge, which has been on trial on hot-rolled strip for six months; and a reflection



Cross-section of the beta gauge, showing the design of the yoke and the traverse system. The chamber and source are mounted opposite each other and are protected by steel foils.

in Metal Gauging

gamma gauge which is at present undergoing trials on heavy cold-rolled strip. Only the first two of these will be discussed at present, but the third will be described when further operational experience has been obtained.

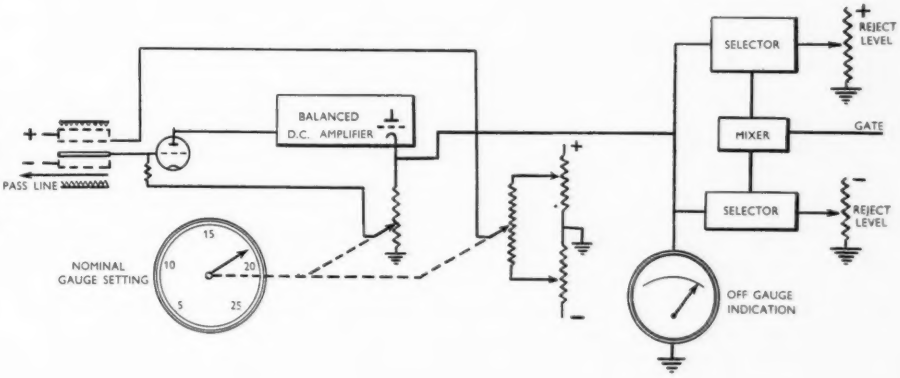
Beta Gauge

The beta gauge developed is designed for use on cold-rolled strip ranging in thickness from 0.005 in. to 0.05 in. steel or 0.005 in. to 0.15 in. aluminium, utilizing either strontium-90 or a ruthenium-106 source. Sr 90, in conjunction with its daughter product, Y 90, is a pure beta emitter having an effective half-life of 28 years. The maximum beta energy is 2.27 MeV and half-thickness is approximately 0.0007 in. steel. Ru 106, in association with its daughter product, Rh 106, has a half-life of one year and an effective maximum beta energy of 3.53 MeV, giving a half-thickness of 0.014 in. steel. These sources are available from the Radiochemical Centre, Amersham, in the form of foil. The active material is rolled in a sandwich of silver, producing a tough, indestructible source of radiation.[1]

and negative side to reject within the limits of ±0.001 in. The probable error in this rejection setting and operation was limited to 0.00005 in. To obtain this accuracy at this speed, a source chamber disposition leaving a free gap of 1½ in. was chosen and two sources each of 50 millicuries of strontium.

Mechanical Construction

To minimize the chance of damage to either the source or chamber by a curled-up edge or cobble, it was decided to use a multiple protection of steel foils. These are all of stainless steel of thickness 0.0006 in. The double chamber itself consists of a cast aluminium box enclosed on the strip side by a cast bronze grille carrying a steel foil gasketed to the body. The opposite face is enclosed by a gasketed plate, to which is soldered on the inside the compensating source. This assembly, together with the electrometer valve, is housed in a cast head unit which on the lower end is sealed by a similar bronze grille with stainless-steel foils Araldited to both sides. Across the outer foil a continuous stream of clean, dry air is blown to prevent build-up of palm oil, etc. A pressure of nitrogen can also be maintained between the outer sealing foils and the chamber to act as a pressure switch, should the outer foils become damaged. Similarly, the source is housed in a cast aluminium box and is protected by a bronze grille

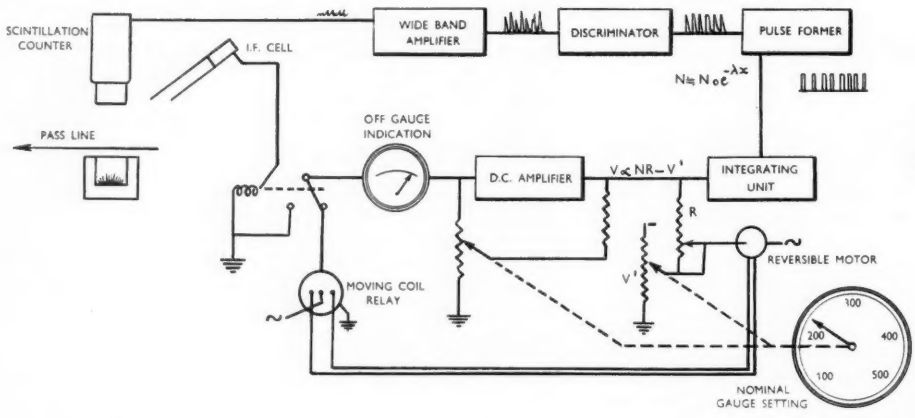


Schematic diagram of the beta gauge, showing the system adopted for adjusting backing-off current to give zero collection current for on-gauge setting and a constant sensitivity of output over the range.

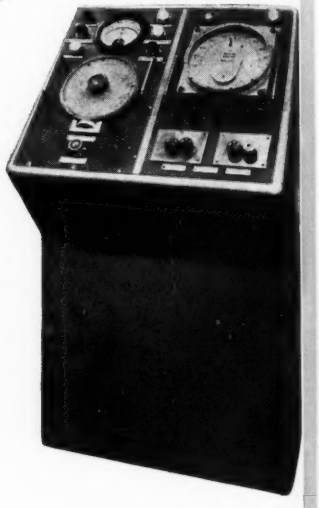
A double ionization chamber is used as the detector, the two sections being enclosed in a common envelope using a common collector electrode. With the very high stability of detection required, it has been found necessary to use an essentially comparative system of measurement using an identical comparator source, and in order to avoid temperature sensitivity to enclose the two chambers in a common envelope. A further innovation is to use a third electrode in the comparison chamber to control the backing-off current. Over a limited range, current flowing to the electrode is a linear function of the voltage applied to the grid and in many aspects the chamber behaviour is like a conventional triode valve. The effective difference current between the two chambers is fed from the common electrode to a d.c. amplifier, the electrometer valve being enclosed in the same head unit as the two chambers.

The original specification around which this gauge was designed called for an operating range of 0.005 in. to 0.025 in., with a probable error of measurement of 0.00005 in. at a time constant of 50 millisec. In order to operate in conjunction with a pin-hole detector on a cut-up line, the output was further required to operate a gate system which could be individually set on the positive

carrying foils on each side. The source unit and chamber are bolted to a cast yoke unit, which for heavy applications is of steel and for lighter applications of aluminium. Apart from robustness, it is essential that the source-chamber spacing is invariable. The system has been designed bearing in mind the necessity for the rapid change of units in the event of a break-down. Chambers and sources have therefore been built to be interchangeable and spares are available as stand-by units. The yoke can be made to traverse either manually, hydraulically or by electric motor. In the illustration the operation is manual and a hand-wheel is included to lock the yoke into position on the carriage. Roller bearings are used to permit easy movement. During the past year a wide variety of mill conditions and process lines has been studied. Whilst some difficulty is experienced on the mill in keeping the outer windows clean, this can be readily got over by suitable wiping at periodic (say four-hourly) intervals. It should be noted that build-up of extraneous matter on the surfaces gives the effect of increasing strip thickness. Equal weights per unit area have approximately the same absorption, so that 0.001 in. of palm oil is equivalent to roughly 0.0001 in. of steel.



(Left) Schematic diagram of the hot-strip gauge, showing the system of re-calibration between individual coils.



Control cabinet for the hot gauge occupying the left-hand side, the right-hand side containing controls and indicators for a width meter.

Electronics

Electrical connections to the head are taken out along the traverse unit to the main electronics unit, conveniently situated in a control room. From this main cabinet additional leads are taken to the control cabinet mounted alongside the line control gear. This console normally is provided with controls for setting the nominal thickness (a potentiometer which sets a voltage applied to the grid of the compensating chamber) and a deviation meter calibrated either as a percentage of nominal thickness or in terms of 0.0001 in. difference from the set gauge. Two tolerance adjustments for setting the positive and negative limits at which the rejection mechanism operates are provided, together with indicator lamps showing the state of operation of the instrument. Provision can also be made for indicating the position of the gauge across the strip.

The main cabinet contains a power pack, a d.c. amplifier and a selector unit. The first two of these are standard to all instruments, whilst the third is adapted to individual conditions depending on whether recorder output, selector control, servo-operation, etc., is required. The units are designed to conform to a rack and panel system to permit easy interchange of units. The amplifier is a d.c.-coupled balanced system with feed-back from the output to the input grid through a high resistance. This high resistance, which demands very high insulation, is mounted in the head unit. The feed-back ratio is ganged with the gauge-setting control to give a constant off-gauge sensitivity at all settings of the gauge.

The Gamma Gauge

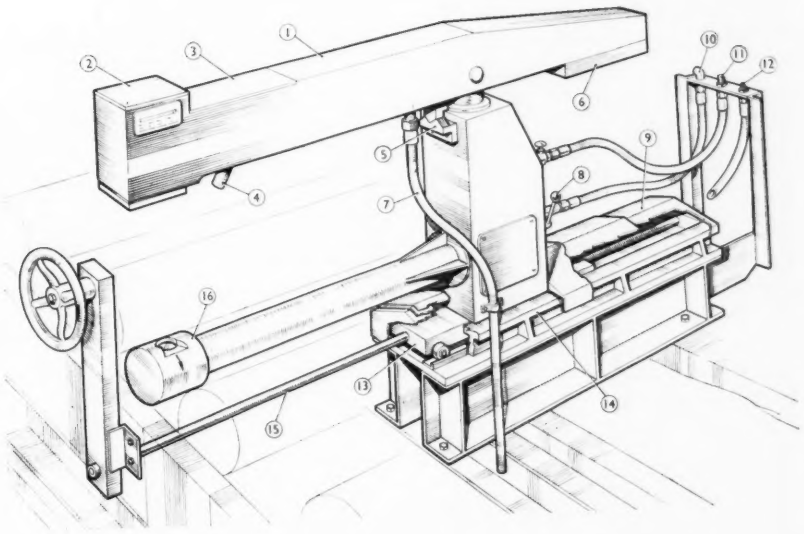
In addition to the problems concerned with protecting a beta gauge against damage due to curled-up edges of the strip and cobbles, the gamma transmission gauge for the measurement of hot-rolled strip in the range of thicknesses 0.050 in. to 0.50 in. steel is designed to operate with strip being rolled at a temperature of, say, 700°C. The detection unit is therefore water- and air-cooled. The source used to cover this range of thicknesses can be either a Bremsstrahlung source, using strontium-90 as the source of beta radiation, and an aluminium target or thulium-170, which emits two characteristic radiations of energies 53 and 84 keV respectively. In either case, the source is compact and can be mounted in one of the rollers on the run-out table. It has been arranged to fit into the bottom of a sealed well in which a nitrogen pressure is maintained. The seal is of 0.050 in. aluminium, over which a continuous stream of clean air is blown. When not in operation, the roller can be rotated through 180° by means

Les Radio-isotopes dans le Calibrage des Métaux

Pour mettre en commun leur expérience de la mesure des radiations et de la construction mécanique lourde, Isotope Developments Ltd. d'Aldermaston et Davey et United Engineering Co. Ltd. de Sheffield ont collaboré à la production de calibres à radio-isotopes particulièrement pour l'installation dans les aciéries. Trois types ont été développés, un calibre béta pour le feuillard laminé à froid, un calibre de transmission gamma pour le feuillard laminé à chaud et un calibre de réflection gamma pour les épaisseurs intermédiaires. Les deux premiers de ces types sont décrits en détail.

La jauge béta que l'on considère être la plus précise et la plus rapide, qu'il soit s'étend sur la gamme de 0,125 mm. à 1,25 mm. avec une précision de 0,00125 mm. près, à une constante de temps de 50 millisecondes. La source employée est du strontium-90 dans la plupart des cas et le groupe de détection consiste en une chambre d'ionisation double dans une enveloppe commune, le courant de compensation étant contrôlé par la tension appliquée à une grille.

Le calibre gamma employant soit une source de thulium-170 ou une source Bremsstrahlung s'étend sur la gamme de 1,25 mm. à 12,5 mm. avec une précision qui dépasse 1% pour une constante de temps d'1 seconde. Le groupe détecteur est un compteur à scintillation monté dans un support fortement armé qui est sur pivot pour lui permettre de basculer hors du chemin en cas d'accidents. La source est placée au fond d'un puits dans la table de sortie et pourra être renversée pour des raisons de sécurité.



View of the radiation gauge used for the continuous monitoring of hot-rolled strip.

of a hand-wheel to give complete protection above the table.

Because of its much greater sensitivity to electromagnetic radiation, a scintillation counter employing a thallium-activated sodium iodide crystal is used as a detector. Pulses from the scintillation counter are fed through a pre-amplifier to the main electronics unit, which is designed to show the mean rate calibrated in terms of steel thickness. A linear wide-band amplifier feeds through a discriminating unit the integrating circuit and d.c. amplifier which, by virtue of a voltage backing-off, gives a plus or minus signal, indicating deviations in thickness from the pre-set value. The output is thus zero when the strip is "on gauge". Hot-strip rolling is a relatively discontinuous process and full advantage is taken of the breaks between individual strips or coils to automatically standardize the instrument. Scintillation counters are temperature sensitive, and at high gain are subject to other small variations in sensitivity. These are generally in the form of slow drifts, and long runs (several hours) can be obtained.

Radio-Isotopen in der Metall Messtechnik

Die Isotope Developments Ltd., Aldermaston, und die Davy und United Engineering Co. Ltd. Sheffield, haben ihre Erfahrungen im Messen mittels Bestrahlung und in der Schwerindustrie ausgetauscht und in Zusammenarbeit Radio-Isotopen-Messgeräte zum Einbau in Stahlwerken herausgebracht. Es sind drei Typen entwickelt worden, ein Beta-Messgerät für kalt-gewalzten Bandstahl, ein Gamma Durchstrahlungs-Gerät für warmgewalzten Bandstahl und ein Gamma Reflexions-Gerät für zwischendurch vorzunehmende Dickenmessungen.

Das Beta-Messgerät, welches, wie man glaubt, das genaueste und am schnellsten arbeitende Gerät ist, umfasst den Beraich zwischen 0,125 mm. und 1,25 mm. mit einer Genauigkeit von 0,00125 mm. bei einer Zeitkonstante von 50 Millisek. Als Strahlungsquelle wird in den meisten Fällen Strontium-90 benutzt, und das Detektor-Gerät besteht aus einer zweifachen Ionisierungs-Kammer in einem gemeinsamen Gahäuse, wobei der Kompensations-Strom mit der Spannung, die einem Gitter erteilt wird, gesteuert wird.

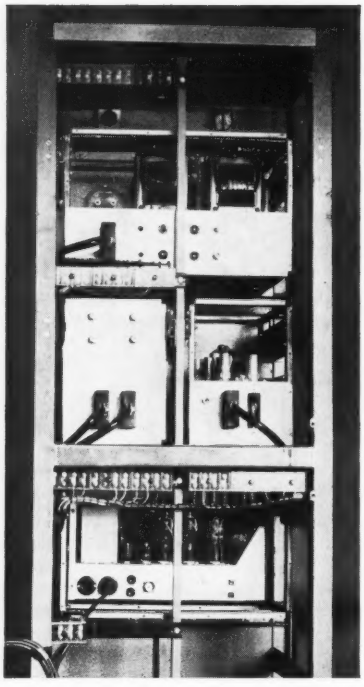
Das Gamma-Messgerät arbeitet entweder mit einer Strahlungsquelle aus Thulium-170 oder mit einer Bremsstrahlungsquelle und umfasst den Bereich zwischen 1,25 mm. und 12,5 mm. bei einer Genauigkeit, die besser als 1% ist, bei einer Zeitkonstante von 1 Sekunde. Als Detektor dient ein Szintillations-Zähler, der in einem schwer gepanzerten Joch montiert ist, das um einen Zapfen drehbar ist, um es in die Lage zu versetzen aus dem Weg heraus zu schwingen, falls ein Unfall eintreten sollte.

Los Radio-isotopos en el Calibraje de Metales

Para combinar la experiencia en medición por radiación y en la ingeniería pesada, Isotope Developments Ltd., de Aldermaston, y Davey y United Engineering Co. Ltd., de Sheffield, han colaborado en la producción de calibradores radio-isotopos particularmente para su instalación en fábricas de acero. Se han evolucionado tres tipos: un calibrador beta para tiras laminadas en frio, un calibrador gamma de transmisión para tiras laminadas al calor y un calibrador gamma de reflexión para espesores intermedios. Los dos primeros se describen en detalle.

El calibrador beta que se cree sea el más exacto y el más rápido disponible, cubre la gama desde 0,125 mm. hasta 1,25 mm. con una exactitud de 0,00125 mm. al constante de tiempo de 50 milisegundos. La fuente empleada es estroncio-90 en la mayoría de casos y la unidad detectora consiste de una cámara doble de ionización en una envoltura común con la corriente de compensación controlada por el voltaje aplicado a una grilla.

El calibrador gamma, empleando ya sea una fuente de tulio-170 o una fuente Bremsstrahlung, cubre la gama desde 1,25 mm. a 12,5 mm. con una exactitud de más del 1% a un constante de tiempo de 1 segundo. La unidad detectora es un contador de centelleo montado en un caballete o soporte fuertemente blindado, el que es pivoteado para permitir que sea virada fuera del paso en el caso de accidentes. La fuente se fija en el fondo de un pozo en la mesa de salida y puede ser invertida para los objetos de la seguridad.



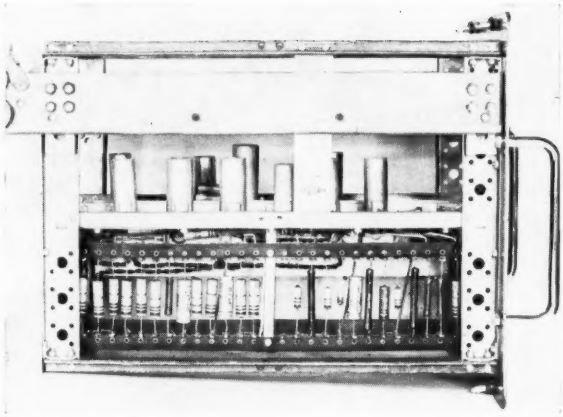
(Right) Side view of the amplifier rate meter unit, showing the open arrangement of components for easy servicing.

(Left) Rear view of the main electronics cabinet for the hot gauge, showing the rack and panel system of construction.

if necessary, between successive standardizations. Furthermore, particularly when using a thulium source, the scintillation counter can be run at a sufficiently high gain to give a plateau in the response. That is, changes in supply voltage or in sensitivity of the tube cause only minor changes in the number of pulses accepted by the discriminator.

To simplify clearing of the run-out table in the event of a cobble, it is necessary to use a large source-detector spacing, and a distance of 20 in. has been taken as a standard. Switching of the gauge to its measuring and standardizing conditions is performed by an infra-red photo-cell, also mounted in the water-cooled head. The head unit itself is heavily armoured and is mounted on a heavy arm which is capable of swinging both in the horizontal and vertical planes, so that in the event of a strip breaking loose and striking it the head will move out of the way without damage, and after the cobble has been cleared can be reset accurately to its original position. The whole unit, consisting of this gantry for the support of the head and the roller for containing the source, can be fixed into the mill run-out table or between stands or can be mounted on a traversing mechanism.

The specification on which this gauge was based called for an accuracy of $\pm$ 1% basic weight at a time constant of 1 sec. In practice, it is probable that this time constant can be increased with corresponding improvement in accuracy, as provision is made in the integrating unit for the output signal to begin each run "on gauge".[2] At the entry of the strip the photo-cell switches the backing-off voltage to the value appropriate to the set gauge figure and momentarily shorts the output so that the off-gauge indicator reads zero. The reading then takes up from this zero position with the set time constant. At the end of the strip the photo-cell switches the backing-off voltage to the value equivalent to zero thickness, momentarily shorts the output again to zero to allow for irregular-shaped tail edges and a servo-system maintains this reading at zero by proportionately varying the sensitivity of the integrating unit. The potentiometer driven by the servo-motor is provided with limit switches to indicate when near maximum gain is attained, showing that the source should be changed, or more probably the window cleaned. A longer time constant can be used during the recalibration time to ensure that the accuracy of setting is greater than the accuracy of measurement. Source strength is calculated to be of the order of 10 mc gamma equivalent when using either a thulium source or a Bremsstrahlung source.



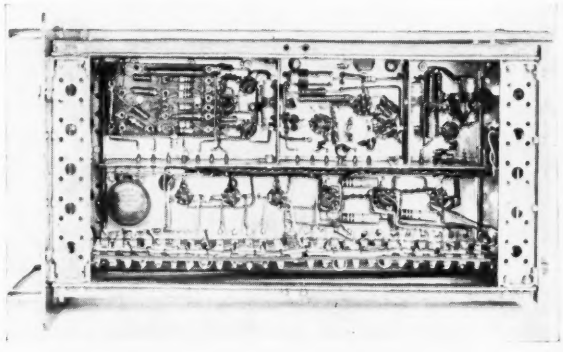
General construction and disposition of the electronics is similar to the beta gauge. The main cabinet is preferably mounted in a clean atmosphere, such as is found in the motor room, and leads are taken off to the console located convenient to the mill operator. Extension meters and controls are provided in the pulpit. The electronics are built on a similar rack principle to allow easy maintenance and easy substitution in the event of damage or failure.

The range of the instrument described does not represent the ultimate that can be obtained. Whilst the standard instrument is operated in the range 0.050 in. to 0.500 in., it can be designed without difficulty to cover the range from 0.020 in. to 2.00 in.

Gauges of this type can be adopted for the mill control, but it is probable that, with the advent of the Automatic Gauge Control system which computes the thickness from the screw-down force, the mill modulus and the screw-down setting, short-term variations will be corrected by this means. It is necessary, however, for an independent system to be used to provide a datum line from which the A.G.C. system can work and a radiation gauge provides the ideal monitor.

References

[1] *Nuclear Engineering*, **1**, 32.
[2] *Nuclear Engineering*, **1**, 245.



Underside view of the R.F. amplifier discriminator and backed-off rate meter.

Computers in Reactor Operation

New Approach to "Processing" Voluminous Data

THE use of computers in the feasibility study and design stages of reactors has rapidly extended during the last few years and is well established. The application of computer techniques to the routine operation of power reactors, however, appears to break fresh ground. By courtesy of Sunvic Controls Ltd., we are able to give brief particulars of a scheme that has actually been developed for the routine observation of fuel-element conditions, but which could quite easily be applied to the "processing" of any other type of information and, in fact, is confidently expected to lead to a new philosophy in this field.

Taking the monitoring of fuel-element channels as a concrete example the scheme consists briefly in the substitution of a computer unit for the recorder system hitherto proposed for such a purpose. In the recorder system, the gas samples from the fuel channel are, of course, cooled, filtered and then introduced to a precipitator unit where the ionized particles within the gas are electrostatically deposited on a tungsten wire which is afterwards withdrawn and presented to a scintillation counter, this indirect method eliminating errors due to short-time activation of the gas itself. From the scintillation counter, the record of activity passes via a ratemeter to a multichannel recorder, where a continuous record of the activity of each channel (or group of channels) is made on a chart.

Whilst this is a practical working proposition, it has been criticized on several grounds. In the first place, the necessity to keep records within practical limits obviously fixes a limit on the size of chart and the instrument sensitivity, i.e., the actual pointer movement for a given change in channel activity. This problem promises to become more serious with the larger reactors now being designed for the new power stations which have many more fuel channels to deal with. Furthermore, it is necessary for every record to be scrutinized at regular intervals, in order to detect any significant changes in activity which will show that trouble is pending.

Computer Techniques

In the scheme developed by Sunvic Controls Ltd., the gas sampling and precipitation apparatus remains unchanged, as does the scintillation counter. A ratemeter, however, is not required and is replaced by a plain scaler unit. From this, discrete counts are fed into a computer unit and recorded on a memory drum, being examined to see if the activity is excessive, in which case the alarm will be sounded. Acceptable levels of absolute activity and differential changes can be preset.

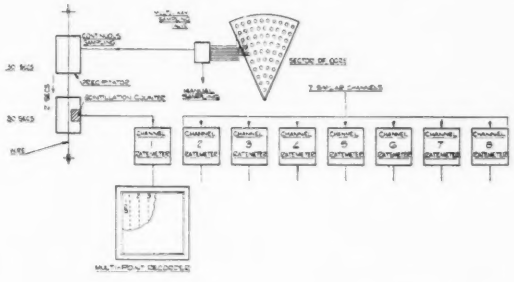
Each computer has associated with it two electric typewriters, one of which prints, at the desired intervals, a complete log of the absolute activity, each count being identified by precipitator, channel group and time. If half-hourly readings are desired, a computer covering 400 groups of channels will print eight readings every half-minute for 25 minutes.

If a damaged fuel element is located, it is usually necessary to investigate its back history and, when required, the second typewriter will give a printed record of the past 24 hours' activity together with the relevant differential and absolute reference levels. This is achieved by means of the memory drum, which automatically keeps a back record for 24 hours, erasing the earliest record and writing in a new one at every half-hourly reading. As previously mentioned, each reading is compared with previous readings, and a "major" alarm is sounded for excessive gas activity, computer failure and motor or supply failure. Minor alarms are sounded for a failure of the rotary valve, faults in the counter or scaler, broken or slipping wire and CO_2 leakage or extraneous γ activity.

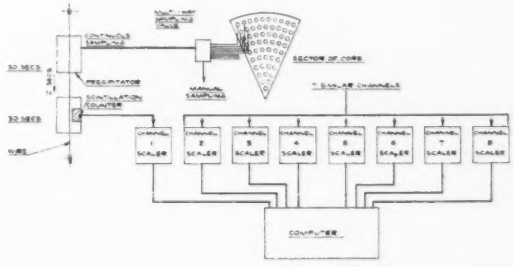
Practical Arrangement

Whilst the computer is designed for maximum reliability, running at only one-tenth the speed of a normal commercial computer, safety dictates the duplication of equipment. In practice, a large power reactor would be divided into a number of segments (say, 16), the duplicate units handling alternate segments so that in the unlikely event of the complete failure of a unit the portion of the reactor covered would still be distributed over its entire area, and not be confined to, say, one side or other of the core. It is possible by operating a change-over switch for, say, No. 2 computer to take over No. 1's readings, and print them, although naturally it cannot take over the automatic comparison with the previous activities, since these are stored in No. 1's memory drum. Reliability of the computer is also assisted by the use of transistors throughout.

An additional advantage put forward for the use of computers is the increased accuracy obtainable. Errors due to ratemeter calibration and zero error are eliminated, since the accuracy of a scaler is dependent only on the statistical count rate error for random pulses and on the input paralysis time. Furthermore, computer information is displayed to three significant figures, which is considerably in excess of that which would be obtained by visual observation of a recorder chart.



(Left) Block schematic of gas-sampling equipment using recorders.



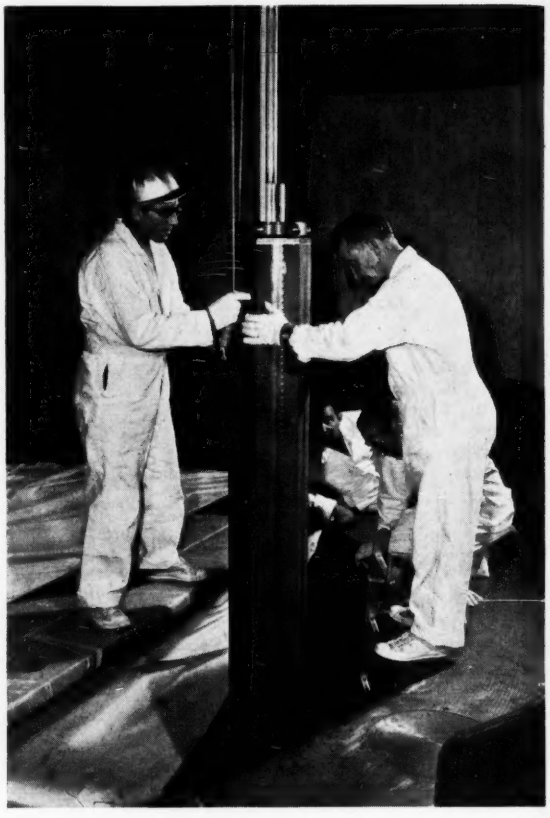
(Right) Block schematic of gas-sampling equipment using computer.

Progress of the S.R.E.

Moderator assembly completed at Canoga Park

ASSEMBLY of the moderator for the Sodium Reactor Experiment is now complete at the Canoga Park laboratory of Atomics International Inc., located in the Santa Susana Mountains in California.

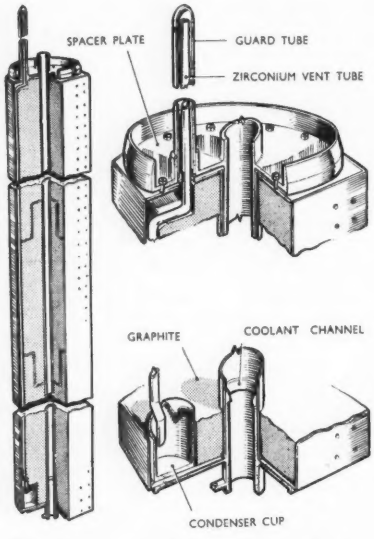
The S.R.E., as first described at the 1955 Geneva conference, was to be a plant with a heat output of 20 MW to obtain operating experience with a graphite-moderated, sodium-cooled unit, and it was originally intended to dissipate the heat in an air-blast cooling system. It was then decided, however, to make use of this output, and the Southern California Edison Co. was authorized to install a 7.5-MW generating set which would feed into its transmission network, the air-blast coolers being replaced in the design by heat-exchanger plant for steam generation.



Lowering the last graphite unit into position on the S.R.E. at Canoga Park.

Canned Graphite

The graphite moderator is probably the most interesting feature of the design, since the liquid sodium coolant would rapidly penetrate the pores of unprotected graphite and it has been necessary, therefore, to arrange the graphite in the form of canned units, the general construction of these being shown in the accompanying illustrations. The units are hexagonal blocks 10 ft. high and slightly under 11 in. across flats, to allow clearance for the coolant.



Zirconium - canned graphite - moderator unit, showing arrangements for gas venting and for trapping condensed sodium.

There are 119 of these elements arranged on an 11-in. triangular lattice in a stainless-steel tank 11 ft. in diameter and 19 ft. deep.

The graphite is machined from large logs approximately 13 in. in diameter, and each unit consists of three portions joined together with plug and spigot-type joints. The canning material is zirconium, since there is a considerable total amount of metal, and neutron economy would not permit the using of stainless steel. The thickness of the zirconium sheet is 0.035 in. for the can sides and 0.1 in. for the ends. A stainless-steel spacer plate and a supporting pedestal are attached respectively to the top and bottom of the can assembly by zirconium studs and nuts.

The central tube, for the fuel element, is of zirconium 2.8 in. in diameter (internal) with a wall thickness of 0.35 in., welded to the top and bottom can heads. This also provides for the main coolant circulation. In addition, the outside of the assembly is cooled by a secondary circulation of coolant between the flats of the hexagons. Mention has already been made of the difference between can dimensions and lattice centres to allow for this, but additional safeguarding is provided by dimples rolled into the zirconium sheet before fabrication of the cans, to ensure that the spaces cannot be closed up due to slight displacement of the moderator elements.

Some of the elements have one or more edges backed off or recessed to provide an additional channel between three adjacent elements for control and safety elements and experimental channels. The diameter of these additional channels is approximately 3¼ in.

Can Venting Arrangements

The flexibility of the thin zirconium sheet, of which the cans are fabricated, requires that they should operate under a slight external pressure so that the can is solidly supported by the graphite. In order to prevent any possibility of trouble due to an internal pressure developing, a ¼-in. vent pipe is provided for each can, protected by a stainless-steel guard tube, this being taken up above the level of the sodium into the helium atmosphere at the top of the tank. A small cup is provided at the bottom end of the vent pipe in order to contain any sodium that might enter as

a result of gaseous diffusion or pressure fluctuations.

The remainder of the S.R.E. reactor has been fairly fully described in the original Geneva conference paper. The project commenced as a joint programme between the U.S.A.E.C. and North American Aviation Inc., of which Atomics International is a subsidiary.

The S.G.R.

A further plant of this type is proposed for the Consumers Public Power District of Nebraska, which will have a thermal output of 240 MW and a gross electrical output of some 80.8 MW.

This reactor would, of course, be considerably larger than the S.R.E., the size of the tank being 17 ft. 6 in. in diameter and 28 ft. 6 in. deep, built of stainless steel 2 in. thick, and containing 233 graphite moderator elements on a 10-in. lattice.

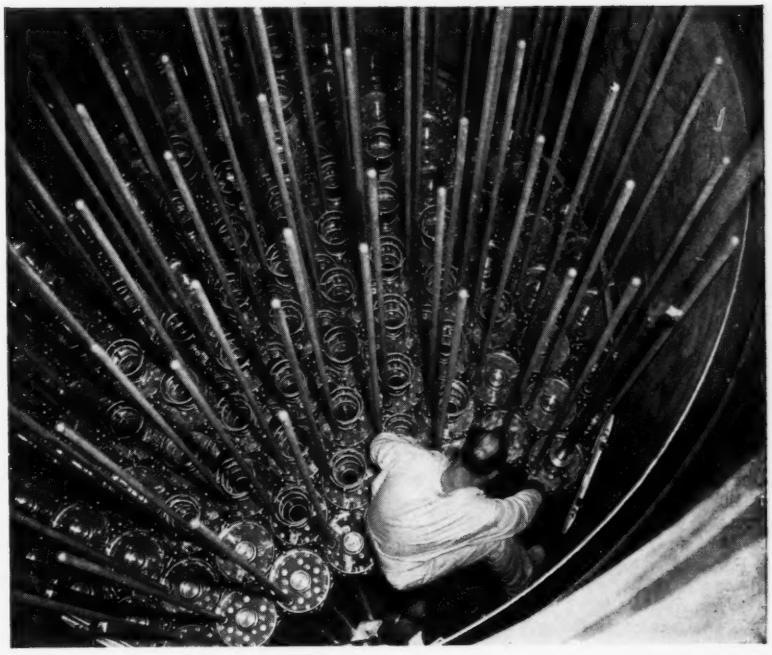
The feature of particular interest about this design is that there are two alternative core designs on which studies are proceeding, although the main differences are in the fuel elements, one being for slightly enriched uranium and the other for thorium-uranium.

The first type of element consists of a cluster of 19 rods, each just under ½ in. diameter (0.455 in.), clad with stainless steel to a total diameter of 0.495 in. Each cluster of 19 rods fits into a coolant tube 3¼ in. in diameter of 0.035 in. zirconium. There are 215 of these elements in the core, each element being 10 ft. long. The uranium itself is in slugs 12 in. long, and the initial enrichment is approximately 1.8% of U^{235}, giving an initial investment of 443 kg.

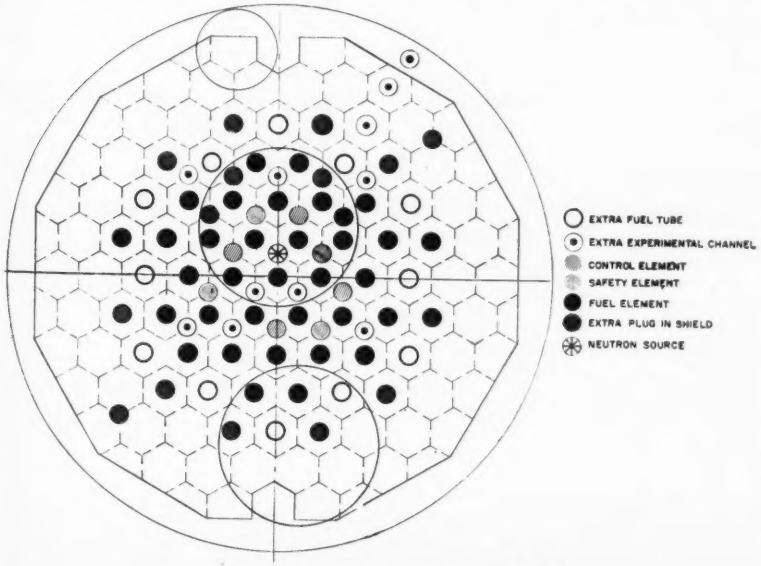
In the thorium-uranium core, the number of fuel elements is 185. The thorium-uranium alloy slugs are 0.648 in. in diameter and 12 in. long, clad as before, but arranged in seven-rod clusters.

The core for the thorium design is smaller than that for the natural uranium, the lattice being 8 in. instead of 10 in., and the number of graphite elements being reduced to 203. This would involve a core diameter of 14 ft. (including reflector) in place of the 17 ft. 3 in. of the uranium-fuelled reactor. The smaller core surface and the substitution of a seven-rod cluster for the 19-rod unit increases the specific heat transfer from 350,000 to 850,000 B.T.U./sq. ft./hr., although the sodium inlet and outlet temperatures remain at 500° and 925/950°F due to the coolant velocity being increased from 9 ft./sec. to 16.2 ft./sec. which increases the pressure drop across the core from 6 to 16 p.s.i., the flow rate, remaining at 6.5×10^6 lb./hr.

The maximum fuel temperatures are given as 1,200°F (649°C) for the uranium rods and 1,600°F (871°C) for the uranium-thorium design. It is pointed out that the limitation on the uranium fuel elements is an α-β phase transition undergone by uranium at 1,220°F with an accompanying volume change. Thorium, on the other hand, seems to hold out possibilities of maximum metal temperatures of up to 2,000°F. Before full advantage could be taken of this, however, considerable operating experience would be necessary, particularly with zirconium, whose physical properties are uncertain for prolonged high temperatures. According to original estimates, although it should be possible to operate thorium up to 2,000°F, the sodium coolant temperature would be limited to 1,200°F. In the plant as proposed at present, the sodium coolant temperature is approximately 950°F and the steam conditions, allowing for two sets of heat exchanger drops, are 850 p.s.i. and 833°F, with feed-water at 300°F.



Looking down into the S.R.E. tank just before completion of the core. The gas vent pipes are clearly seen, as well as the coils on the top of the cans for guiding the fuel elements into position.



Plan of the reactor core of the S.R.E.

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*[In the article "Industrial Enterprise", describing work in progress at the Renfrew works of Babcock and Wilcox Ltd., (December, 1956, page 371) the weight of the N.P.D. reactor vessel and its head were given as 20 tons and 10 tons, instead of 210 tons and 70 tons respectively. The error is regretted.—*ED.]

World News

Berkeley and Bradwell nuclear stations get under way. Upper view, John Laing and Son Ltd. make a start on the Berkeley site. Lower view, Lord Citrine breaks the ground at Bradwell. With him is Mr. Robin McAlpine.

UNITED KINGDOM

Small packaged-power reactors will be available from British sources before very long, following arrangements made between Humphreys and Glasgow Ltd. and Alco Products Ltd., who engineered the APPR reactor. The arrangements, announced on January 29, give Humphreys and Glasgow Ltd. the sales rights outside N. America. These reactors, modelled on the APPR design, will be of the pressurized-water type, with a net electrical output of 2, 5, or 10 MW. A 25 MW design is in hand.

For further information on the APPR (Army Package Power Reactor) see *Nuclear Engineering* for July, 1956, p. 149. A picture of the unit approaching completion appears on p. 82 of this issue. It is due to commence operation in 1957.

Work has commenced on both the Bradwell and Berkeley sites. At Bradwell, Lord Citrine inaugurated the work on January 18, as the guest of the Nuclear Power Plant Co. Ltd. The public inquiry on the Hunterston site for the South of Scotland Electricity Board was due to commence on January 29, so the G.E.C. Simon-Carves group is still held up so far as site construction work is concerned. The A.E.I.-John Thompson group commenced work at the Berkeley site on January 7.

Contracts for the constructional steelwork for Berkeley power station have been placed with the constructional steel division of Vickers-Armstrongs (Shipbuilders) Ltd. (Palmers Hebburn works).

A conference on heat utilization from nuclear reactors was held at the A.E.R.E., Harwell, on January 18, attended by representatives from Government departments, research establishments and the chemical industry.

A new company, Nuclear Graphite Ltd., has been jointly formed by A.E.I.-John Thompson and the Morgan Crucible Co. Ltd. which will specialize in the machining of graphite blocks for nuclear purposes. A capacity of 8,000 tons of raw graphite per year is envisaged; this could be expanded by shift working.

AUSTRALIA

An exhibition and demonstration of atomic power developments is to be held in Brisbane in 1958, sponsored by the British Government. According to the Brisbane *Telegraph*, it will be one of the largest ever held in the Commonwealth.

The report in our November issue regarding possible sites for nuclear power stations has still not been confirmed. A statement made by the Premier to *Nuclear Engineering's* own correspondent in South Australia states that the Electricity Trust is still investigating several likely sites, but it is not likely that any specific location will be selected for some considerable time.

GERMANY

Exploitable uranium deposits have been found in at least two places in the Rhineland-Palatinate, it is reported.

HOLLAND

Main exhibit of the A.E.A. at "Het Atoom", the International atomic energy exhibition to be held in Amsterdam from July this year, will be a model of Calder Hall, 18 ft. long.

A new firm, Atomelektra A.G., has been set up with the ultimate object of constructing an atomic power station. The engineering concern of Elektro-Watt A.G. is behind the venture.

ISRAEL

The twentieth conference of the Israel Physical Society, held in Haifa, devoted a considerable amount of its time to nuclear physics. Lecturers included scholars from the University of Jerusalem, the Haifa Institute of Technology, the Weizmann Institute of Science, Rehovot, and the Israel Atomic Energy Commission.

The Weizmann Institute of Science, Rehovot, has established a course on the use of isotopes in industry, agriculture and chemistry. This institute, incidentally, will be the location of the Seventh International Congress on the Structure of the Atom.

ITALY

A pressurized-water reactor and power plant rated at 134 MW (electrical) is being ordered by the Edison-Volta organization of Milan. It is reported that a contract has been placed in the U.S. with Westinghouse Electric International for a duplicate of the plant to be built for Yankee Atomic Electric Co., a group of New England utilities, at Rowe, Mass.

(Right) Schoolboys examining a model of Calder Hall on the *Daily Telegraph* stand at the Schoolboy's Own Exhibition.

(Left) The reactor house for the West German swimming-pool reactor nearing completion at Munich.

JAPAN

Naval architects of the Mitsubishi Company have commenced the design of two nuclear-powered oil tankers, one surface and one submarine type. The surface tanker will be 47,000 tons dead-weight and the submarine 30,000 tons, the respective speeds to be 17 and 22 knots. A sodium graphite reactor is proposed for the surface vessel; no decision has yet been reached on the submarine.

A 10-MW heavy-water reactor for the research centre at Takai (60 miles from Tokyo) is to be built by A.M.F. Atomics Inc. in association with the Mitsubishi group.

SWITZERLAND

Estimated expenditure of CERN (European Organization for Nuclear Research) for 1957 is 61.8 million Swiss francs as against 39.6 million for 1956. This is due to the increased construction activity at Meyrin, where the synchrocyclotron is expected to be in operation before the end of the year.

SOUTH AFRICA

South Africa's potential uranium production has been grossly underrated, it is stated in a report from Johannesburg. Present annual production is believed to be some 4,500 tons of oxide, equivalent to 3,285 tons of metal.

TURKEY

Istanbul University is to have a nuclear reactor built with U.S. aid. At present, the type and output is still under discussion.

VENEZUELA

Swimming-pool Reactor for Venezuela. The Venezuelan Biophysics and Nuclear Physics Research Centre is to have a 5-MW swimming-pool reactor which will provide a wide variety of experimental facilities. The reactor itself is being manufactured by General Electric (U.S.A.), and the General Nuclear Engineering Corporation of Florida will design the housing and act as consultants for the experimental requirements.

U.S.A.

Radiation Effects Colloquium. The Office of Naval Research of the U.S. Navy Department and the Glenn L. Martin Co. are joint sponsors of a meeting to be held at Johns Hopkins University in Baltimore from March 27-29, when a series of papers will be presented on the general subject of radiation effects on materials.

The homogeneous reactor which was installed at the Armour Research Foundation, Chicago, last summer (*Nuclear Engineering*, August, 1956, p. 198) was recently taken out of service for modification by the manufacturers, Atomics International, to increase the efficiency of gas recombination. It is now back in operation again.

Uranium oxide production from ore mills in the U.S. has doubled over the past twelve months, according to an A.E.C. report, and is now 8,000 tons per year. Ore reserves in the U.S. are estimated to be some 60 million tons, of which more than 68% is in New Mexico.

A new boiling-water research facility at the A.E.C.'s National Reactor Testing Station in Idaho is to cost 8½ million dollars. Known as ARBOR (Argonne Boiling Reactor Facility), it will form an extension of the work carried out by the Argonne National Laboratory, which includes BORAX and EBWR. The new facility will consist of a core, pressure vessel, condensers, heat exchangers, pumps and auxiliary equipment, designed to allow the simulation of a wide range of operating conditions.

The heavy-water plant at Dana, Indiana, is to be closed down, it being felt that future requirements for heavy water can be met by the A.E.C.'s other plant at Savannah River, S.C. This latter plant, of later construction than the Dana equipment, has lower production costs. It also has the advantage of more corrosion-resistant construction; Dana having been subject to a certain amount of trouble from corrosion. The older plant will be shut down slowly, over a period of some nine months, and will be preserved in a "stand-by" condition.

A swimming-pool-type research reactor is proposed for a location about 4½ miles from Princeton, N.J., and the A.E.C. has given notice of its intention to issue a licence to A.M.F. Atomics Inc., ownership later being transferred to a group of industrial concerns. The reactor, which will be capable of operating up to 5 MW, will be generally similar to the Bulk Shield Test Facility in operation at Oak Ridge since 1951, but will have a stall at one end and movable gates to divide the pool into two sections; the stall containing beam holes and a thermal column. A dry irradiation chamber,

The APPR reactor being built by Alco Products Inc. at Fort Belvoir, Va., nearing completion. A description of this 2-MW pressurized-water plant was given in *Nuclear Engineering* for July, 1956.

using spent fuel elements for a γ-ray source, is to be built into the far end of the pool. A net amount of 63.8 kg of contained U 235 is to be allocated.

The submarine "Nautilus" is expected to refuel within the next few weeks. It is still operating with the original fuel with which it commissioned, and has travelled some 60,000 miles.

General Electric is stated to be expanding its facilities for the production of irradiated polythene from 300,000 lb. per year to some 1½ million lb., eventually to be expanded to more than 3 million lb. per year.

Thorium of high purity is being produced in small quantities, it is reported by Metal Hydrides Inc., of Beverly, Mass.

Cracking due to stress corrosion will delay the starting up of the homogeneous reactor HRE2 at Oak Ridge. The cracking, which is microscopic, was first observed in the leak-detector system during preliminary testing, and further examination disclosed evidence of similar damage to flanges in the high-pressure system to which the detector system is connected. It has been ascribed to chloride ion contamination of the stainless steel. The reactor itself is not affected, but starting-up may be delayed until the autumn, if extensive flange replacement seems necessary.

The A.E.C. has decided not to provide assistance for three out of seven proposals for small-capacity plants proposed in response to the second invitation of the Power Reactor Development Programme. These are the City of Holyoke's gas turbine nitrogen coolant proposition, the City of Orlando's liquid-metal-fuel scheme and the 500-kW pressured light-water scheme for the University of Florida. Negotiations are, however, under way for the other four projects; the 22-MW closed-cycle boiling-water plant for the Rural Co-operative Power Association of Elk River, Minnesota; the 5–10-MW aqueous homogeneous plant for Wolverine Electric Co-operative of Big Rapids, Michigan; the 10-MW heavy - water - moderated, sodium - cooled unit jointly proposed by the Chugach Electric Association of Anchorage, Alaska; and Nuclear Development Corp., of America, White Plains, N.Y., and the 12.5-MW organic-moderated scheme for Piqua, Ohio.

The EBWR (Experimental Boiling Water Reactor) at Argonne National Laboratory had a test run at full power (20 MW heat, 5 MW electricity) on December 29. Construction was completed in November and criticality was achieved on December 1. This is the first of the five projects initiated in 1954, under the A.E.C.'s civilian power reactor development programme, to generate electricity.

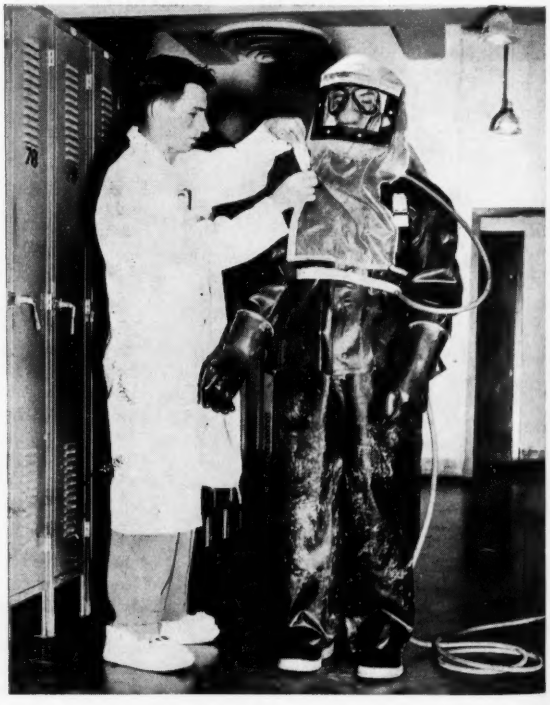
Notice has been given of the proposed issue of a permit to the Westinghouse Electric Corporation for the construction of a testing reactor in Sewickley Township, 29 miles south-east of Pittsburgh. The reactor will be of the pressurized-water type using enriched uranium, and will have a heat output of some 20 MW.

Grants for foreign nations. Details of the scheme for assisting friendly nations with grants of up to $350,000 for reactor research projects have been distributed to overseas embassies. Grants have already been made to Brazil, Spain, Denmark and the Netherlands, and negotiations are proceeding with other nations.

Uranium on loan. The A.E.C. has approved loans of 5,500 lb. of uranium metal in the form of aluminium-sheathed rods to four further universities and technical institutes, to be used in subscritical assemblies for training purposes. This brings the total number of loans up to 12.

International co-operation in prospecting. The A.E.C. is fostering co-operation with friendly nations in the field of uranium exploration by making information on geology and exploration techniques generally available and by encouraging geologists and technicians to visit the U.S. and study uranium deposits and projects.

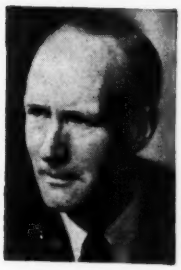
Spent fuel elements are to be used by Sinclair Research Laboratories for work on irradiation processes.



Preparing to enter a highly contaminated zone in the Hanford (U.S.A.) plutonium plant, this General Electric employee wears 18 protective garments.

Lord Mills.

Sir John Cockcroft.



Sir Christopher Hinton.

Mr. W. L. Owen.

Mr. W. Barr.

Personal

Sir Percy Mills, who has been appointed a Cabinet Minister in charge of a new ministry, the Ministry of Power, was until this appointment chairman of W. and T. Avery Ltd. and of Lancashire Dynamo Holdings Ltd., and a director of Babcock and Wilcox Ltd. and of Electrical and Musical Industries Ltd. Sir Percy, who is not a politician, has been created Baron Mills of Studley to enable him to hold Cabinet office.

Mr. J. M. Bazin, formerly contracts manager of A.E.I.-John Thompson Nuclear Energy Co. Ltd., has been appointed export manager of the company. He is succeeded as contracts manager by **Mr. F. Field.**

Lord Bicester has been elected a director of Associated Electrical Industries Ltd.

Sir Summers Hunter has retired from the board of Richardsons, Westgarth and Co. Ltd., the parent company of the Richardsons Westgarth Group. Sir Summers has been elected honorary president of the North Eastern Marine Engineering Co. Ltd., which is the company in the Group with which he has been associated. **Mr. Harry Hunter** also retires from the parent board, but will continue as a member of the boards of the North Eastern Marine Engineering Co. Ltd. and George Clark and North Eastern Marine (Sunderland) Ltd. **Mr. J. E. Smith,** managing director of North Eastern Marine, and **Mr. G. L. Hunter,** marine sales director of the Group, have been appointed to the board of the parent company. **Mr. A. H. I. Kinsman,** a member of the parent board, has been appointed to the board of George Clark and North Eastern Marine (Sunderland) Ltd. **Mr. P. Kendra,** works manager at the Southwick works at Sunderland, is also named a director of that board. **Mr. A. D. McN. Boyd** has been appointed land sales director, and **Mr. E. A. Eborall** and **Mr. J. E. Lee** regional directors of Richardsons Westgarth (Hartlepool) Ltd.

Mr. A. Rolander, Jr., deputy director of security for the U.S. Atomic Energy Commission, has joined General Dynamics Corporation's General Atomic Division as assistant to Dr. Frederic de Hoffman, a vice-president of the corporation and division general manager of General Atomic.

Mr. E. L. Halle, M.I.Mech.E., a consulting engineer with the Morgan Crucible Co. Ltd., has taken up an appointment as a consulting engineer with Peregrine and Partners, consulting engineers.

Mr. H. A. Springer, A.M.I.E.E., has been appointed joint managing director of Sangamo Weston Ltd. Mr. Springer became a director of the company in 1953.

Col. B. A. Austin, M.I.Mech.E. M.I.Prod.E., has been appointed chief engineer to Isotope Developments Ltd. Col. Austin has recently retired from R.E.M.E. and will be responsible for the overall co-ordination of production, development, applications and research in the field in which I.D.L. are working.

Sir Noel Ashbridge, B.Sc. (Eng.), a past president of the Institution of Electrical Engineers, has been elected to honorary membership. Also elected was **Brig.-Gen. Sir Harold Hartley,** G.C.V.O., C.B.E., M.C., M.A., F.R.S. The Council of the Institution has made the thirty-fifth award of the Faraday Medal to **Dr. Waldemar Borgquist,** lately president of the Swedish State Power Board.

Lt.-Col. L. A. M. Bates-Oldham has been appointed a special director of International Combustion Ltd.

Mr. R. D. Parker has been elected a director of the International Nickel Company of Canada Ltd., succeeding **Mr. J. S. Duncan,** C.M.G., who has resigned in view of his recent appointment to the post of chairman of the Hydro-Electric Power Commission of Ontario. Mr. Parker was formerly a vice-president of the company.

Mr. C. R. Corness has been appointed secretary of Taylor Woodrow Construction Ltd. in succession to **Mr. L. Daniels,** who continues as secretary of Taylor Woodrow Ltd., the parent company. **Mr. L. G. Cann** has been appointed deputy chief surveyor of Taylor Woodrow Construction Ltd.

NEW YEAR'S HONOURS LIST

Order of Merit

Sir John Cockcroft, member of the board, United Kingdom Atomic Energy Authority, and director, Atomic Energy Research Establishment, Harwell.

Knights

Mr. John Norman Dean, chairman, Telegraph Construction and Maintenance Co. Ltd. **Mr. Josiah Eccles,** deputy chairman (Operations), Central Electricity Authority. **Col. Jackson Millar,** part-time member of the South of Scotland Electricity Board. **Mr. W. L. Owen,** director of engineering, U.K. Atomic Energy Authority Industrial Group. **Mr. F. J. Pascoe,** chairman of South Wales Switchgear Ltd., Aberdare Cables Ltd., and chairman of British Timken Ltd.

K.B.E.

Sir Christopher Hinton, member of the board, U.K. Atomic Energy Authority, and managing director of the U.K.A.E.A. Industrial Group.

G.C.V.O.

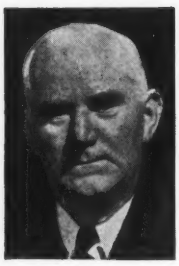
Brig.-Gen. Sir Harold Hartley, president, World Power Conference; former president, British Association for the Advancement of Science.

C.B.E.

Mr. A. A. Fulton, general manager, North of Scotland Hydro-Electric Board. **Mr. A. T. Green,** director of research, British Ceramic Research Association. **Mr. O. W. Humphreys,** director, Research Laboratories of the General Electric Co. Ltd. **Mr. Robin McAlpine,** director, Sir Robert McAlpine and Sons and associated companies. **Lt.-Comdr. J. W. Thornycroft,** managing director of John I. Thornycroft and Co. Ltd. **Mr. J. F. Loutit,** director of Radiobiological Research Unit, Harwell.

O.B.E.

Mr. W. Barr, technical director, Colvilles Ltd. **Mr. W. M. Court-Brown,** director, Group for Research on General Effects of Radiation, Medical Research Council. **Mr. E. G. James,** leader of Valve Group, G.E.C. Research Laboratories, **Dr. H. Kronberger,** chief physicist Research and Development Branch, U.K.A.E.A. Industrial Group. **Mr. J. Nadin,** general manager and director, D.P. Battery Co. Ltd. **Mr. A. E. Roots,** manager, Ayrshire area, South of Scotland Electricity Board. **Mr. H. K. Worship,** general manager, Thorpe Road works of Laurence Scott and Electromotors Ltd.



Sir Thomas Eades.

Mr. R. N. Millar.

Sir Alexander Roger has retired from the board of Automatic Telephone and Electric Co. Ltd. and has accepted the appointment of honorary president of the company. **Sir Thomas Eades**, formerly managing director, has succeeded Sir Alexander and **Mr. C. O. Boyse** has been appointed managing director.

Mr. Forbes Jackson, M.I.E.E., who has been vice-chairman since 1954, has been elected chairman of the Wiring Regulations Committee of the Institution of Electrical Engineers.

Dr. Gerald Keech, who recently received his Bachelor of Philosophy in physics at McMaster University, Hamilton, has accepted a position with Atomic Energy of Canda Ltd. at Chalk River.

Mr. V. S. Risoe, M.B.E., has been appointed a director of Associated Electrical Industries Overseas Ltd. and has resigned from the boards of Associated Electrical Industries (India) Private Ltd. and Associated Electrical Industries Manufacturing Co. Private Ltd.

Mr. Miles Beevor has relinquished the post of joint managing director but retains the deputy chairmanship of the Brush Group Ltd. **Mr. Ian T. Morrow**, joint managing director, has been appointed managing director, and **Mr. Charles Barnard**, formerly managing director of Mirrlees, Bickerton and Day Ltd., has been appointed to the board of the Brush Group Ltd. **Mr. M. C. Clear** has also been appointed to the board as director in charge of exports.

Mr. J. D. Peattie, B.Sc., F.C.G.I., M.I.E.E., acting chief engineer of the Central Electricity Authority, who has been appointed chief engineer retrospectively as from January 1, 1956, has retired. **Mr. F. H. S. Brown,** B.Sc., (Hons.), M.I.Mech.E., M.I.E.E., generation design engineer of the Authority, has been appointed chief engineer in succession to Mr. Peattie. **Mr. E. S. Booth,** M.Eng., M.I.Mech.E., M.I.E.E., generation station construction engineer, has been appointed deputy chief engineer (design and construction) and **Mr. J. C. Duckworth,** B.A., nuclear power engineer, deputy chief engineer (nuclear power).

Mr. C. Murray, deputy overseas manager for Australia, New Zealand and the Americas for British Insulated Callender's Cables Ltd., has been appointed manager (overseas). **Mr. W. H. McFadzean,** chairman and managing director of B.I.C.C., is on a world tour on behalf of the company.

Dr. D. C. Moore and **Mr. E. A. Taylor,** of Imperial Chemical Industries, have been awarded the Sir William J. Larke Medal for 1956 by the Council of the Institute of Welding for their paper on "The Welding of Copper and Copper Alloys".

Professor P. M. S. Blackett, Professor of Physics at the Imperial College of Science and Technology, London, was installed as president of the British Association for the Advancement of Science, at Birkbeck College, London.

Mr. R. F. Mayne has retired from the Micanite and Insulators Co. Ltd., where he had been manager of the mica department for 34 years. He is succeeded by **Mr. A. W. Townsend,** who had been his assistant. Mr. Mayne has served for many years on the management committee of the Mica Trade Association.

Mr. R. N. Millar has been appointed assistant general manager of Fraser and Chalmers Engineering Works, Erith, and will continue to be manager of the G.E.C. Simon-Carves Atomic Energy Group.

Mr. E. G. Clarke, managing director of Acheson Colloids Ltd., has been elected to the board of directors of Acheson Industries Inc. of New York, the parent company.

Mr. Eric N. Adlington has been appointed deputy managing director of Temple Press Ltd. He has been with the company for 31 years and a member of the board of directors since 1948.

OBITUARY

It is with deep regret that we announce the death of **Mr. G. N. Roberts,** Helsby works manager of British Insulated Callender's Cables Ltd.

Meetings to Note

February 5.—I.E.E. (East Scotland Sub-centre, at the Carlton Hotel Edinburgh): "The Control and Instrumentation of a Nuclear Reactor", A. B. Gillespie.

February 6.—I.E.E. (South-west Scotland Sub-centre, at 39 Elmbank Crescent, Glasgow): "The Control and Instrumentation of a Nuclear Reactor", A. B. Gillespie.

February 6.—I.E.E. (London Education Discussion Circle): Informal discussion on "The Place of Liberal Studies in Sandwich Education", opened by E. H. Horrocks.

February 7.—I.E.E. joint meeting with Civils and Mechanicals: "The Place of Engineering in University Education" (Third Graham Clark lecture), Sir Ifor Evans.

February 7.—Institute of Metals (London section, at 17 Belgrave Square, S.W.1): "Beryllium", Bengt. Kjellgren.

February 12.—Society of Instrument Technology (Manchester section, at Manchester College of Technology): "Computing Technique Applied to Measurement and Control", J. Wills.

February 12.—Institute of Metals (South Wales section, at Department of Metallurgy, University College, Swansea): "Neutron Irradiation Effects in Metals", Professor J. G. Ball.

February 13.—Manchester Metallurgical Society (Central Library, Manchester): "Titanium", J. W. Rodgers.

February 15.—Institution of Mechanical Engineers (in conjunction with the B.N.E.C., at Church House, Westminster): The Thomas Hawksley Lecture, "Some Engineering Problems in the Industrial Development of Nuclear Energy", Sir Claude Gibb. (Tickets only.)

February 18.—Institute of Metals (Sheffield section, at Engineering Lecture Theatre, The University): "Radiation Damage to Metals", W. M. Lomer.

February 19.—Society of Chemical Industry (Birmingham group) (joint meeting with Institution of Chemical Engineers (Midlands branch) at Midlands Institute, Paradise Street): "Some Aspects of Atomic Energy", C. M. Nicholls.

February 19-21. — Institution of Mechanical Engineers' Conference (at Central Hall, Westminster): "The Mechanical Engineer's Contribution to Clean Air". (Registration required.)

February 21.—I.E.E. (South-west Subcentre, at Electricity Showrooms, Bedford Street, Exeter): "Nuclear Energy and Electricity Generation", G. T. Shepherd.

February 26.—Society of Instrument Technology (London section, at Mansion House, Portland Place, W.1): "The Determination of Parameters of a Controller by Simple Frequency Measurements", J. H. Westcott.

February 28.—Institute of Metals (Birmingham section, at the Engineering Centre, Stephenson Place): "Nickel Alloys with Special Properties in the Field of Physics and Electrical Engineering", C. Gordon Smith.

The Faraday Lecture

This year's Faraday lecture, "Nuclear Energy in the Service of Man", is being given by Dr. T. E. Allibone at the various I.E.E. Sub-centres on the following dates:

February 6.—Leicester (De Montfort Hall).

February 11.—Southampton (Guild Hall).

February 13.—London (Central Hall).

March 1.—Liverpool (Philharmonic Hall).

March 5.—Belfast (Sir William Whitla Hall).

March 25.—Leeds (Town Hall).

March 28.—Edinburgh (Central Hall).

April 2.—Newcastle (City Hall).

April 9.—Manchester (Free Trade Hall).

Orbits in Industry

January should have gone down in history as the month when site work commenced on all three power stations. As the Scottish site is still subject to the decisions of a public inquiry, however, only Berkeley and Bradwell were started. In itself, this is no mean achievement. There are many nations who would have felt pretty proud to have started even one nuclear station of half the size.

A.E.I.-John Thompson were first off the mark with the Berkeley site, because the N.P.P.C. waited to hold a small inaugural ceremony, with Lord Citrine to cut the first sod on the Bradwell site; rather a nice thought in these days of ruthless utility. After all, one does not commence a nuclear power station every day of the week, and to let the occasion pass unmarked is rather like launching a ship without a bottle of champagne. There was, however, nothing old-world about the ceremony; no bunting, no potted palms, and no silver spade. Lord Citrine drove a bulldozer, and the piece of turf he removed, instead of the lady-like tablespoonful usual on these occasions, was about a couple of tennis-courts worth.

An unorthodox ceremony requires an unorthodox finish. Since there was no silver spade, it was not possible to present it to Lord Citrine and a bulldozer might prove an embarrassing gift, particularly with the oil situation as it is. The problem was solved, however, by the presentation of a small clockwork model, so everybody was happy.

A Race?

It was a bold challenge that Sir Claude Gibb flung to his competitors, incidentally, in prophesying that Bradwell would be the first truly economical station in the world to go into regular service. This is no sprint, where the result is decided by the competitors' first leap as the pistol bangs; it is more of a five-miler, where almost anything can happen.

If there really is a race, it should provide all the makings of a good film plot. We should like to see the way Hollywood might handle the scenario. One can picture the goings-on between rival organizations; the masked figures creeping on to the sites at dead of night to cut crane cables; the fake fuel elements full of dynamite; the final scene where the chairmen of the respective companies fight it out, man to man, with rolled umbrellas on the jib of a crane high above the site . . . but real life is much less colourful, unfortunately.

Gas-filled Reactor?

Driving on to the Bradwell site for the ceremony, the first thing that caught one's eye, besides the huts, was what seemed to be a miniature of the Dounreay sphere, and we wondered idly if the N.P.C.C. had produced a small industrial reactor even more compact than the APPR for site power. It was, in fact, the site power; as the coach drew nearer one could read the inscription—it said CALOR-GAS. Possibly more practical, but technically disappointing. The other would have made a much better story.

Portents?

One final irrelevancy, before we leave the Bradwell site for the present. It is within gunshot of St. Peter's Chapel where, so legend has it, Christianity was first brought to these islands. Although it might be slightly blasphemous to draw a comparison, it seems a good omen, doesn't it?

Jobs for the Boys

It is fashionable nowadays to describe schoolboys as sophisticated little beasts, but when one sees some of the things "laid on" for them nowadays, it is difficult to see how they could possibly be otherwise, unless they possessed the wisdom of several Solomons—and that they never have done (no, not even *your* contemporaries!). Wandering around the *Schoolboy's Own Exhibition*, it was curious to reflect that many of the items assembled to amuse them would have caused no little stir at a Royal Society's Conversazione only a few years ago, so rapidly does a scientific marvel become a commonplace.

Even more impressive, however, was the accent on careers. To those of us who grew up in an industrial depression, the idea of large and powerful organizations competing for the services of youngsters still seems little short of miraculous; yet this aspect is beginning to overshadow the amusement side of the exhibition. Particularly noteworthy was the exhibit staged by the *Daily Telegraph* which had, as its theme, "Atomic Energy as a Career" and, in conjunction with the Atomic Energy Authority, had a remarkably interesting display of models, with a representative of the A.E.A. on hand to advise on careers, armed with a very full range of literature.

Whilst on the subject of careers, a booklet *Chemical Engineering, a Career* has just been issued by the Institution of Chemical Engineers, which does not make the mistake of imagining that every boy knows already what a chemical engineer is and does, but really explains the subject, as well as reviewing the main methods of training. It is good to realize that a very wide circulation amongst careers masters is intended; chemical and nuclear engineering are too closely interwoven for us to lose any opportunity of enlisting the bright boys.

Tell it to the Machines

Passing over the computers that translate from one language to another, and the usual rumour about one that actually thinks for itself (how often have a combination of clever programming and the facility for self-checking been mistaken for these Frankenstein stories?), the most significant development that has taken place for some time, in our opinion, is the Sunvic Controls' application, rather cursorily reviewed elsewhere in this issue. This is much more significant than would appear at first glance. Its importance lies not in the particular application, nor in the improved accuracy obtainable, but in the underlying philosophy of handing over a vast mass of minute-by-minute readings and leaving it to the machine to decide—within its terms of reference—what is of vital importance, and what is of transitory interest only, and acting accordingly. Thinking on these lines, there would seem to be no limit—except economics—to the extension of this technique. It should be possible to design a computer system to take entire charge of a gas-cooled reactor, not only detecting faulty elements but, having located the doubtful channel, arranging for it to be emptied and replaced by a fresh string—or even tracking down the actual element and replacing that alone.

Further developments would give the machine complete control of the station, being fed with information regarding Grid requirements, control-rod positions, coolant temperatures, blower speeds, steam pressures, etc., even down to weather forecasts, so that it could make the necessary corrections for changes in condenser vacuum.

Where computer control would probably pay the greatest dividends, however, is in the marine field, where the possibility of sudden changes in output due to the manœuvrability requirements is considerably greater than in a land-based station.

Industrial Notes

Technical Overseas Services Ltd., of 7 Queen Anne's Gardens, London, W.5, has been formed to assist British manufacturers in finding new markets overseas, and to direct overseas buyers to the appropriate British manufacturer, also by acting as consulting engineers. They have offices in Rome, Düsseldorf and Paris.

Hastings and St. Leonards Technical College now has its administrative offices situated at Uplands, Archery Road, St. Leonards (telephone Hastings 3847).

British Oxygen Gases Ltd. have established three new store depots for compressed oxygen and dissolved acetylene at Highland Haulage Ltd., Longman Garage, Inverness; D. M. Wallace and Sons Ltd., Bownmount Engine Works, Kelso; Londonderry and Lough Swilly and Letterkenny Railways, Londonderry. Arrangements for drawing supplies will be made through the Scottish headquarters at Polmadie, Glasgow.

Atomic Power Constructions Ltd., the new group composed of International Combustion (Holdings) Ltd., Crompton Parkinson Ltd., Richardsons, Westgarth and Co. Ltd., Trollope and Colls Ltd. and Holland, & Hannen and Cubitts, has established its new headquarters at Beaconsfield House, 28 Theobalds Road, London, W.C.1 (telephone CHAncery 7466).

Vacu-Blast Ltd. has established a French company, Société Vacu-Blast (France), at 46 rue Anatole France, Levallois-Perret (Seine).

Moxey Ltd. is the new name of The Moxey Conveyor and Transporter Co. Ltd., of 13 Augustus Road, Birmingham, 15 (telephone Edgbaston 3575). The London office is at Dunster House, Mark Lane, London, E.C.3.

High Voltage Engineering Corporation of Cambridge, Massachusetts, announces that Van de Graaff machine prices have been increased by an average of 10%. This company is represented in Britain by High Voltage Servicing Co. Ltd., of 142 Twyford Road, West Harrow, Middlesex.

The Baldwin Instrument Co. Ltd., of Brooklands Works, Dartford, Kent, has registered the name "Atomat," associated for a long time with its range of nucleonic thickness gauges, as a trademark.

Acheson Colloids Ltd., of 18 Pall Mall, London, S.W.1, has opened a new plant, Acheson Colloiden N.V., at Scheemda, Groningen, The Netherlands.

Air Control Installations Ltd., of Ruislip, Middlesex, has moved its Birmingham office to Wolverley House, Digbeth, Birmingham, 5 (telephone Midland 5148).

DIDO CONTRACTORS

In our January account of DIDO, there are a couple of errors amongst the names of contractors taking part. The supplier of the "Boral" should have been given as High Duty Alloys Ltd., of the Hawker-Siddeley Group. Similarly, the manufacturers of the gas scrubbers should have been given as Peabody Ltd., of 300 Vauxhall Bridge Road, London, S.W.1.

PUBLICATIONS

Heat - resisting Alloy. — "Calmet" chrome-nickel alloy steel is described in a brochure issued by the Calorizing Corporation of Great Britain Ltd., of Lynton House, Tavistock Square, London, W.C.1. Attractively produced, it illustrates many applications of this heat-resisting material in furnace and superheater work and in chemical and oil-refinery units. Tables and curves give complete technical data on properties and performance.

Vacuum Pumps.—Leaflets describing the Heraeus high - vacuum Roots - type pump for use in vacuum metallurgical equipment, received from Fleischmann (London) Ltd., of 16 Northumberland Avenue, London, W.C.2, who are the sole distributors in Great Britain for these German-made pumps.

Flexible Tube and Hose.—*Arteries of Industry* is a new quarterly publication issued by the Compoflex Co. Ltd., of 23 Northumberland Avenue, London, W.C.2, as an extension of their advisory service.

"Machine Tool Lubrication." — Published by Wakefield-Dick Industrial Oils Ltd., of 67 Grosvenor Street, London, W.1, this 96-page book is a new addition to the Wakefield-Dick technical series and deals very thoroughly with different types of machines and bearings; in addition to a brief introduction to the fundamentals of friction and lubrication, notes on hydraulic systems, gears, and factory lubrication organization.

Metallurgical Grinding and Polishing.—Fine grinding machines, two-speed grinder - polishers and self - contained polishing benches, together with samples of abrasive papers and cloths, are described in leaflets received from the Shandon Scientific Co. Ltd., of 6 Cromwell Place, London, S.W.7.

Apprenticeship.—Manual of engineering apprenticeship training received from Richardsons Westgarth and Co. Ltd., of Hartlepool, describing the works of the various companies comprising their group. Details are given of the training available in marine, general, turbine and electrical power engineering.

"Lead in Atomic Energy."—Latest in the series of information pamphlets issued by the Lead Development Association, of Eagle House, Jermyn Street, London, S.W.1, this publication deals in a comparatively non-technical manner with radiation shielding by lead and lead glass.

Laboratory Apparatus.—No. 26 of the *BTL Bulletin*, published by Baird and Tatlock (London) Ltd., of Freshwater Road Chadwell Heath, Essex, contains articles on automatic Karl Fischer titration apparatus, electrolysis and gas content apparatus, in addition to a number of other new units.

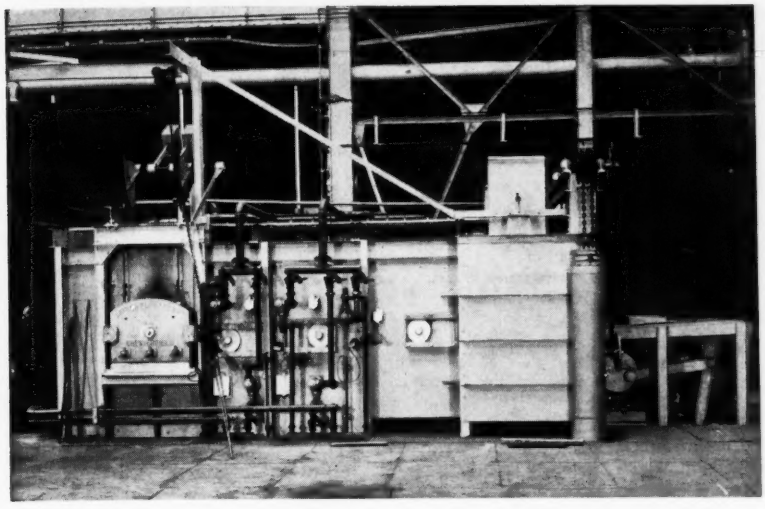
Organic Reagents for Metals.—"Thorin" for thorium, lithium and zirconium and "Dithizone" for lead are described in two monographs received from Hopkins and Williams Ltd., Chadwell Heath, Essex. The former is stated to enable thorium to be detected spectrophotometrically in concentrations as low as 1 microgram per ml.

Complete Atomic Power Plants.—A brochure received from Alco Products Inc., of Schenectady 5, New York, describes the capabilities of the organization to supply complete reactor power plants, and illustrates the company's criticality facility; the pressurized-water cycle; a heat-balance diagram; and a "transvision" cut-away illustration of the Army Package Power Reactor under construction for the A.E.C.

World Export.—The General Electric Co. Ltd., of Magnet House, Kingsway, London, W.C.2, have issued a 48-page brochure, giving a brief account of exports to the world under the headings of plant and machinery domestic equipment, heating and ventilation, communications, cables, lighting, and instruments. It is scarcely necessary to say that illustration and general production are of the expected standard.

Shot Cleaning for Heat Exchangers.—"Tornado" shot-cleaning plant for heat-exchanger surfaces (Ekstrom system) is described in a leaflet issued by Keith Blackman Ltd., of Mill Mead Road, Tottenham, London, N.17.

Processes and Equipment



This town's-gas-fired continuous pusher-type furnace, by British Furnaces Ltd., has been installed by Kayser, Ellison and Co. Ltd., Sheffield, 4, in their new 10½-in. double-duo-type rolling mill. The company is able to produce in their own plant anything from ingots to cold-drawn wire of very small diameter.

Graphite Block Heat Exchangers

A series of large, rectangular, graphite block heat exchangers has been added to the Delanium range made by Powell Duffryn Ltd., 8 Great Tower Street, London, E.C.3. The three new models are basically similar in design to the other cubic heat exchangers, except that the dimensions of the graphite block have been extended and the flow patterns modified to suit the altered shapes They have effective surface areas of 100, 150 and 200 sq. ft. and tube or hole diameters of ¾ in.

Multiple-pass arrangements of up to 16 passes on each side are available to suit the flow rates of both liquors, and also to ensure minimum pressure drop.

Oscillating Hoists

A series of automatic oscillating hoists for use over quench treatment baths, degreasers, washing tanks, etc., is now being made by Martonair Ltd., Parkshot, Richmond, Surrey. The air-operated hoists have all the features of the standard Martonair units with check valves to prevent the load dropping should the air supply fail.

The magnitude and position of oscillation is variable to give any length of oscillation at any position of the lift within the capacity of the hoist, adjustment being provided by trips mounted on the side of the piston. A pair of airflow regulators govern the speed of oscillation for both raising and lowering. The normal maximum speed up or down is 1 ft./sec. The number of oscillations depends on both speed and magnitude and, with an oscillation of 1 ft. at the maximum speed, 30 oscillations per minute can be obtained.

The hoists are provided with both hand and automatic operation and are available on five models of loads from 120 lb. to 500 lb. They are normally fitted with four-wheel articulated trolleys, but double eyebolt mountings are also available.

Pneumatic Timers

The range of applications for Square D pneumatic timers has been increased by the introduction of a d.c. version to supplement existing a.c. types. The operating principle of this kind of instrument is based on the interval necessary to transfer a small volume of filtered air from one chamber to another through a regulated orifice. Adjustments are provided from 0.2 sec. to 3 min. in an infinite number of steps. The pneumatic unit is so designed that it is virtually impervious to fluctuations in atmospheric pressure and ambient temperature.

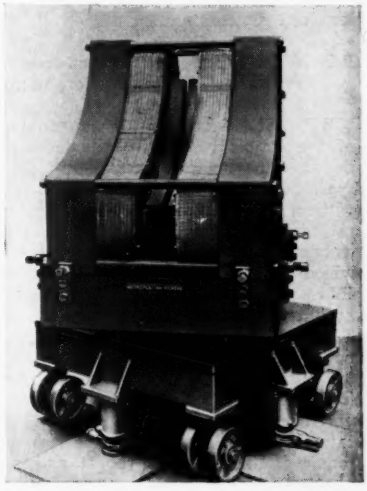
The new timer is available with operating coils for up to 250 V d.c. and embodies all the features of the a.c. model. It is a compact device and flexible in operation, as simple adjustments enable the time setting to be varied and also to convert the device from time delay after energization to time delay before energization and vice versa. One or two auxiliary switches, operating directly from the timer magnet, can be fitted: these normally consist of a double-circuit contact mechanism.

The makers are Square D Ltd., 100 Aldersgate Street, London, E.C.1.

Beam-bending Magnets

Two sets of beam-bending magnets used to deflect the vertical beam of charged particles emerging from an electrostatic generator through 90 degrees into the horizontal direction have been built by Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester, 17, for the Atomic Weapons Research Establishment, Aldermaston.

Each of the large magnets provides a flux density of 12,500 gauss in a 1-in. air gap between kidney-shaped pole pieces of surface area of about 150 in². The energizing coils are wound from hollow aluminium conductors, through which cooling water is circulated at a rate of 2 g.p.m. The electrical input is about 6½ kW and the weight 5¼ tons. There are two of these installations on successive floors, apertures being left in the base plates of the magnet and in the floor to allow an undeflected beam to pass through to the set on the lower floor.



Large Metropolitan-Vickers beam-bending magnet for the Atomic Weapons Research Establishment, Aldermaston.

The smaller magnets used to direct the deflected beam on to one of three target areas provide a flux density of 12,500 gauss in a 1-in. air gap between wedge-shaped pole pieces and are also water cooled.

Both large and small magnets have adjustable pole pieces to vary the angles of entrance and exit of the beam relative to the boundary of the magnetic field.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 761,369. Cobalt-base alloy and its manufacturing process. To: Office Nationale d'Etudes et Recherches Aeronautiques (France).

A cast cobalt-base refractory metal alloy for use at high temperatures. The following formula is given:

Co	...	...	$\geqslant$ 39% by weight
Cr	...	...	20 to 35%
Mo	...	...	5 to 20%
W	...	...	0 to 10%
Ni	...	...	3 to 15%
C	...	...	0.3 to 1.2%
Ti	...	...	0 to 0.5%
Zr	...	...	0.05 to 0.3%
Si-Mn	...	...	< 3% (with Si 0.5 to 2% and Mn 0.5 to 1.2%)
Fe	...	...	< 6%

The cobalt-base solid solution is present in two allotropic forms; in face-centred cubic or alpha form and in close-packed hexagonal or beta form. Articles are cast slightly smaller than designed; under mechanical strain at a temperature in the neighbourhood of the working temperature they then attain the predetermined dimensions.

B.P. 761,926. Self-powered semi-conductive devices. To: Radio Corporation of America (U.S.A.).

B.P. 761,404 contains the description of the irradiation of a semi-conductive body with nuclear radiations. This specification discloses power production without irradiation by incorporating raidoactive emitter material, i.e., one or a combination of radioactive isotopes which emit charged particles and/or E.M. radiations (e.g., polonium and uranium, strontium-90 or tritium, cobalt). The thickness of the semi-conducting body is selected so that substantially all the radioactive emission incident on the body is absorbed. The self-powered unit has a number of advantages. No external power sources or batteries are required. The unit is robust and not affected by vibration or mechanical shock. It is very small—of the order of a cubic centimetre—and has an extremely long life. (Additional to B.P. 761,404.)

B.P. 761,766. Treatment of irradiated substances. A Charlesby and M. Ross. To: U.K. Atomic Energy Authority.

When substances of high nuclear weight characterized by a chain structure (polythene) are irradiated with high energy neutrons, gamma rays, X-rays or other high energy radiation such as thermal neutrons, the solubility of these substances in organic solvents is reduced, as is also the tendency to melt and flow (B.P. 732,047). It has been observed that the mechanical properties of the irradiated substance alter rapidly with temperature, and the cause has been found to be, at least in part, the presence of low molecular weight substances formed during irradiation. By treating the substances by solvent extraction or by heating at low pressure, a substantial reduction in the amount of low molecular weight substances is obtainable.

B.P. 762,519. Production of titanium or zirconium. L. J. Derham. To: National Smelting Co. Ltd.

Refers to the production of the metals by continous reaction in a reaction vessel between the vapour of sodium or potassium and the vapour of titanium or zirconium tetrachloride (B.P. 736,852). The process is improved by lining the reaction vessel with titanium or zirconium respectively before passing the reactant vapours therein. The heat generated in the vessel may be controlled by the introduction of chlorine.

B.P. 762,757. Sealing metal tubes by pressure welding. F. Andrews and B. N. Clack. To: U.K. Atomic Energy Authority.

Corrodible metals like aluminium and aluminium-rich alloys are difficult materials to cold pressure weld. Small-bore Al tubing is almost impossible to weld by this technique, because neither mechanical nor chemical cleaning can with certainty destroy the heavy tenacious oxide film on its surfaces. By (locally) swaging the tube in the region where the weld is to be made, so that the cross-section is reduced sufficiently to disrupt any oxide film on the internal surfaces, sealing by cold pressure welding becomes possible. Figures are given for a pure Al tube of 2.5 mm o.d. and 0.2 mm thickness reduced to 1.45 mm o.d. with an increased wall thickness of about 0.5 mm using wedge-shaped hardened-steel cutting blades for the sealing step and the parting-off. The method is applicable to the manufacture of radon radiographic sources, radon-filled nasopharyngeal applicators, envelopes of vacuum tubes, Geiger counters, etc.

B.P. 762,867/868. Circuits using point-type transistors. E. H. Cooke-Yarborough. To: U.K. Atomic Energy Authority.

A circuit in which the voltage across the load decays rapidly through the second transistor when the first transistor is switched off (762,867). As a time-delay circuit or a multi-vibrator (762,868).

B.P. 763,184. Apparatus for inductive prospecting. To: Canadian Airborne Geophysics Ltd. (Finland).

A single aircraft (aeroplane or helicopter) is used carrying a transmitter and a transmitting coil, but the receiving coil is situated in a streamlined case which is towed at the end of a long, thin cable. By suitably shaping the case and making it heavy, the cable will hang downward at a fairly steep angle. The nearer to the surface of the earth the receiving coil can be kept, the stronger become the radiation anomalies caused by the ores. In order to reduce wind resistance, the multi-wire cable required for transferring the voltage induced in the receiving coil to the aircraft may be replaced by a single thin steel wire and the signal transmitted by radio.

B.P. 763,185. Apparatus for airborne electromagnetic prospecting. To: Canadian Airborne Geophysics Ltd. (Finland).

This specification refers to the arrangement of the radio transmitter in the "bird or glider" towed by the aircraft as described in B.P. 763,184.

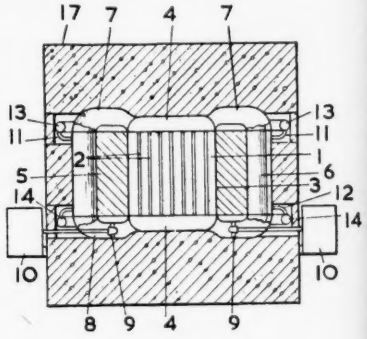


Fig. 1. B.P. 763,231.

B.P. 763,231. Nuclear reactor power plant. S. G. Bauer and C. D. Boadle. To: U.K. Atomic Energy Authority.

Fissile material in suspension or dissolved in a liquid metal is circulated through a heat exchanger. The heat is transferred to a further liquid metal and secondary liquid-metal circuit may be used either directly for heating, or for heating water in a further heat exchanger to raise steam. Fig. 1 shows a cylindrical core structure (1) (mass of beryllia 148 cm long, 148 cm diameter) with bores (2) having a total cross-section of 1,240 cm^2 in a domed steel drum (3). 5 is a partial reflector of graphite, beryllia or water. Heat exchangers (6) are connected by (7) and (8) to the core. A flow rate of 248 l/sec. is maintained by motors (10) in this primary circuit. The secondary flow circuit includes connections (11 and 12) and ring mains (13 and 14). The primary circuit is filled with a 1.05% solution of uranium-235 in 6 tons of molten lead. The secondary circuit contains molten sodium. The reactor is estimated to provide 100 MW heat output at a sodium outlet temperature of 600°C.